SCIENCE AND LIFE IN THE WORLD

Science and Civilization

The Future of Atomic Energy

VOLUME I

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THE GEORGE WESTINGHOUSE
CENTENNIAL FORUM

SCIENCE AND LIFE IN THE WORLD

VOLUME I

Science and Civilization
The Future of Atomic Energy

VOLUME II

Transportation—
A Measurement of Civilization
Light, Life, and Man

VOLUME III

A Challenge to the World

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THE
GEORGE WESTINGHOUSE
CENTENNIAL FORUM
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SCIENCE AND LIFE IN THE WORLD

Science and Civilization
The Future of Atomic Energy

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Dedicated to

THE STATESMEN, SCIENTISTS, AND INDUSTRIAL LEADERS OF THE WORLD, WITH WHOM RESTS THE RESPONSIBILITY OF USING WISELY MAN'S KNOWLEDGE OF NATURE'S FORCES

THE GEORGE WESTINGHOUSE CENTENNIAL FORUM

THE GEORGE WESTINGHOUSE CENTENNIAL FORUM, held in Pittsburgh on May 16, 17, and 18, 1946, to commemorate the one hundredth anniversary of the birth of George Westinghouse—one of America's most renowned inventors and industrialists—constituted a most significant gathering of distinguished scientists, scholars, and leaders in the world of industry. Twenty-four leaders in the field of science and technology were invited to participate in a remarkable symposium that summarized all of our current knowledge and pointed the way toward future research and development. Many of the speakers were intimately connected with the tremendous research and development in all fields of science brought about by the Second World War. The summary of the new knowledge thus gained, together with its implications for the present and future generations, is the theme of all of these significant papers. In these volumes are offered, to all specialists in the fields of science and sociology as well as to the general reader, a verbatim transcript of each of these addresses. In them will be found a thorough analysis of the perplexing problems of our day.

FORUM ADVISORY COMMITTEE

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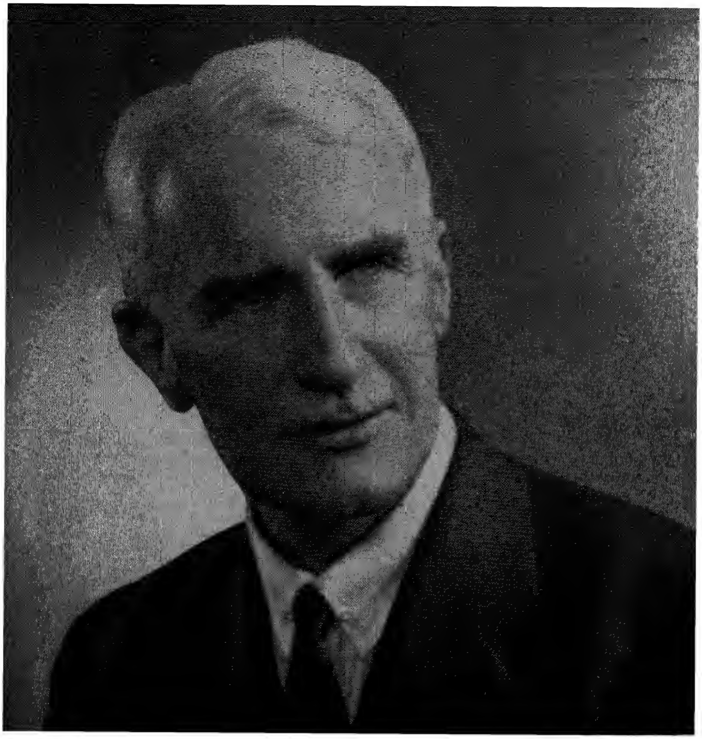
Science and Civilization

Scientific Ethics

BY

DR. A. V. HILL

Foreign Secretary of the Royal Society, England



Dr. A. V. Hill, *Foreign Secretary* and research professor (biophysics), Royal Society, University College, London. Honorary fellow of King's and Trinity Colleges, Cambridge; Nobel Prize winner, physiology and medicine, 1922; appointed to British Order of the Companions of Honour "for scientific services," 1946. As special air attaché at British Embassy in Washington, 1940, made preliminary plans for pooling scientific war information between Britain and the United States. Associated with Society for Protection of Science and Learning, aiding academic refugees. Member of Cabinet Scientific Advisory Committee. Former member of Committee of Award, Commonwealth Fund Fellowships; chairman of Executive Committee, National Physical Laboratory; Member Parliament for Cambridge University, 1940–1945.

Scientific Ethics

I AM DEEPLY GRATEFUL TO THOSE WHO ORGANIZED THE George Westinghouse Centennial Forum for the invitation that brought me here today and for all the kind and efficient courtesy with which arrangements for the visit were made. One advantage of the scientific life is that wherever in the world one goes, and I have made the experiment often, one finds friends.

It is six years since I was in the United States and Canada, and the times are very different now from May, 1940, when I was pretending to be an assistant air attaché in Washington. Then we had to live on faith, for there wasn't apparently much else to live on except a good fighting spirit, but the universal friendship which an English scientist, in whatever disguise—and nobody was deceived—experienced here in those grim days, which was indeed one of the chief agents in maintaining his faith, is exactly the same today. May I take this opportunity therefore of saying, "Thank you," not only to the Westinghouse Educational Foundation, but to all the American scientists with whom we in England have had the happiness and privilege of friendship and collaboration.

I am, I think, the only visitor from England who has come directly to this Forum. Another who had hoped to come sent me, the day before I left, a letter that I know you would like me to read. George Nelson, the chairman and managing director of the English Electric Company,

wrote: "Unfortunately, owing to the negotiations in connection with the acquisition of the Marconi Company, I am unable to take the trip. It would have been the greatest pleasure: firstly, because I knew George Westinghouse; secondly, because, although we have no financial interlinkage whatever, my company and Westinghouse have a research and interchange agreement which both of us value very greatly, not only because it is a contribution to scientific development, but as a link between our two great English-speaking nations; and thirdly, because recently, at a great gathering at which I was being honored in the States, it was found that I had the longest association, except in one case, with the Westinghouse organization. I should be glad if you would convey to the Forum my sincere regrets that I am unable to be present and my conviction that the Forum will form a great link between the English-speaking peoples and, through this, will lead to the further technical, economic, and sociological advancement of the world. I hope you have a wonderful trip." I am having it!

The last time I spoke to a gathering of this size was in 1932, in Rome. There was an International Congress of Physiologists and I had to give the inaugural address. To my astonishment, when I reached the hall, one of the great historic halls in Rome, the doors had been locked. Mussolini had decided to take the chair and had arrived two or three minutes before me. After much excitement, I was finally dragged in through a window and, somewhat breathless, presented to Il Duce. He received me very affably and said he had always followed my work with the greatest interest; to which I answered more truthfully that he could not have followed my work with as much interest as I had followed his, which apparently he took as

a compliment. Then we were photographed together, he sitting under a statue of Julius Caesar. I have not been dragged into the Syria Mosque through a window this morning; our chairman today is not a bit like Mussolini, and, although we have been photographed, he was not sitting under a statue of anybody!

But now for scientific ethics.

Scientific discovery and its technical application make up a kind of self-propagating process, each new gain supplying the means or the impulse to the next one. A chain reaction may peter out; or it may grow indefinitely in speed and intensity; or it may be subject to inherent or intelligent control, by which the action of each element in exciting the next one is kept within the limits of stable operation. Scientific discovery in the past has sometimes flared up locally and then died down again; its average trend for several centuries has been a gradual rise, but the process has never run away with itself.

Today, however, when the pursuit of science is worldwide, when communication is rapid, and when individual comfort and well-being and national wealth, prestige, and security are involved, there are obvious signs of a change in the motive, the tempo, and the character of scientific advance. Can it be that the speed and intensity of scientific discovery, and its technical application without sufficient ethical restraint, have now reached the limit beyond which man—who is really just the same in physical, mental, and emotional make-up as he was thousands of years ago—will be unable to absorb and control them? Will the products of human reason, ingenuity, and skill, accumulating with ever-growing speed, combine with human irresponsibility to set up a final grand explosion in which civilization will perish?

History can show many examples of regional civilizations that grew and flourished and then somehow became unstable and disappeared; and paleontology, many examples of biological species that prospered for a time and then died out. There is a strong tendency in the human mind, particularly in America and England, to reflect complaisantly, "Ah, yes, but those things never happen to us." Perhaps the last few years may have taught some of us a lesson; they very nearly did happen to us. It is not necessary that our civilization or indeed that man himself should survive. The conditions of survival of man as a biological species, and of his civilization, involve a totally new factor in biology, the use of organized reason and accumulated knowledge. It was that which made the various civilizations possible, and its perversion helped at intervals to bring them to an end.

Optimists genially suppose that such reason and knowledge inevitably increase human progress and the stability of human affairs. If those were used simply for the common welfare, to assist in the common struggle against the forces of nature, undoubtedly they would. It is too easy, however, to employ them in exactly the contrary way, in order to gain temporary advantage of wealth or power. It is all too easy to use reason and knowledge to produce and propagate unreason and mistrust; to employ their resources not for maintaining law but for organizing lawlessness, for increasing and not decreasing the entropy of human society. This idea of inevitable progress, popular not so long ago, is one of the most dangerous of illusions, founded as it is on a romantic disregard for facts. What is inevitable rather is general breakdown and disorder, unless decent honest men in all countries work together all the

time to preserve and improve our common inheritance of civilization.

The dominating factor in human relations is the balance at any time between reason and emotion. In the past, in spite of frequent disturbances, the general course of history was tolerably stable; reason played, for good or for ill, only a minor part. If men were not very reasonable, at least they could not pervert knowledge for producing general disorder and destruction. But biological systems, like those of inorganic nature, may have more than one position of equilibrium, and we like to fancy that another stable state exists toward which we are gradually tending. That state, we imagine, is one in which reason will play a more substantial part, no longer chiefly the handmaiden of emotion and prejudice or the conscript of exploitation and tyranny. But how are we to get there? Can gradual progress achieve it? Or is a supreme effort, a sudden jump, required now?

It is in the nature of things that between two positions of equilibrium there lies an energy barrier or a region of instability. The chief difficulty is that, so long as unreason in the main determines human conduct, it will seek to use reason as its tool; and the more potent the reason, if used for unreasonable purposes, the greater the damage it can do. Reason in fact cannot help us over the barrier unless it pulls in the right direction and not the wrong. The energy available in human society for social betterment and moral and intellectual change varies from time to time; in conditions of long stability it is low, while in the ferment of today it is momentarily very high. It might be great enough now, if rightly directed, to get mankind over the hump between Reason and Unreason. In the uniqueness of

the present opportunity lies its urgency; unless we seize it, it may not come again until after a fresh disaster, even worse than that of recent years. Indeed another such disaster, if reason growing in material power but not in moral direction compromises with unreason, may leave civilization in ruins, with the bandits and international gangsters on top. We have had, in fact, a very close shave.

This is an age of scientific discovery and technical achievement and we are here today to celebrate the life and work of George Westinghouse, a pioneer in their application to human comfort and security. Westinghouse was possessed not only of superlative ingenuity and skill in engineering and invention but of remarkable vision and courage in their application. Perhaps equally important in the development of his great enterprises was his consideration and respect for human labor and those who worked with him. That tradition remains a characteristic of his organization. He was in fact an outstanding example of leadership in the movement of the last hundred years that has given us today such vast opportunities—if only we can take them—for the betterment and broadening of human life. We do right indeed to honor his memory.

But in spite of past achievement and present opportunity it is not all lovely in the garden, and world events particularly since 1933 have forced on scientific men many questions which in their final analysis are ethical, not scientific. Some may think it merely a sign of approaching old age to have chosen "Scientific Ethics," instead of something more practical and up to date, as the title of this talk. At any rate I am in good company, for the scientific community, young and old alike, not least in America, are deeply concerned about this very matter. I yield to none in estimation of the benefits that scientific discovery

and the scientific habit of mind could bring to human society, and I am never so happy myself as when working in a laboratory. But science, like patriotism, is not enough; the moral values remain, and without them civilization would be a barren humbug. Perhaps a compensation for gray hairs is that a growing incredulity about universal nostrums for curing human ills brings one nearer back to reality.

One advantage of science as a calling is the universal cogency of its methods and results. All sensible men everywhere finally agree about the facts, and race, religion, and political opinion have no bearing at all on them or their interpretation. Such certainty is impossible about other judgments, and in ethical values much depends upon group tradition and individual experience. All decent men, however, will agree that certain moral values are needed in a stable, free society—for example, those of honesty, kindness, tolerance, and courage—and, if scientific men are not to become the agents and tools of the unreason that may prevent mankind from climbing over the hump to the promised land, they need to ponder on the ethical imperative of their work. Otherwise the chain reaction of scientific development, exploited for unreasonable or selfish purposes, may tumble us all back into universal chaos. We cannot hope to stay just as we are, trusting the magic of words, the witchcraft of politics, or the illusion of inevitable progress to pull us through; positive morality and a courageous determination to apply its precepts are the only guides to safety, indeed the only insurance against continuing tragedy in human affairs.

Some seventeen hundred years ago there crystallized out, from many centuries of experience of the ethical necessities of medicine, the so-called Hippocratic Oath.

You will know it already, but may I read you a few sentences of it?

> The regimen I adopt shall be for the benefit of my patients according to my ability and judgment, and not for their hurt or any wrong. I will give no deadly drugs to any, though it be asked of me, nor will I counsel such. . . . Whatsoever house I enter, there will I go for the benefit of the sick, refraining from all wrongdoing or corruption, and especially from any act of seduction. . . . Whatsoever things I see or hear concerning the life of men, in my attendance on the sick or even apart therefrom which ought not to be noised abroad I will keep silence thereon, counting such things to be as sacred secrets. Pure and holy will I keep my life and my art.

Of Hippocrates himself, who lived hundreds of years earlier, we know very little for certain, but this is what a modern historian writes of him.

> Learned, observant, humane, with a profound reverence for the claims of his patients, but possessed of an overmastering desire that his experience should benefit others; orderly and calm, anxious to record his knowledge for the use of his brother physicians and for relief of suffering; grave, thoughtful and reticent; clear of mind and master of his passions.

Then he adds pertinently:

> While the philosophers developed the conception of a rational world, it was the physician, typified by Hippocrates, who first put it to the test of experience. It was they, the physicians, who first consciously adopted the scientific process which, in relation to medicine, is called the Hippocratic Method.

The care of the sick and injured, of mothers and children, of the aged and powerless; the sanctity of human life; the insistent claim of suffering and danger; these are part of the ethical tradition of medicine. Its practitioners may sometimes fail to live up to the moral responsibility of

their calling, but at least such failure is regarded as dishonorable, and the place of the doctor in society shows how generally his obligation of humanity is fulfilled. It is hard indeed to imagine any kind of civilization without an ethical basis to medicine, without the imperatives and restraints of medical custom and tradition. Medicine, like astronomy, was the first of all the natural sciences. It was the mother of many of them, and it remains the most difficult. It is surely, therefore, of extreme significance that tradition has attached to the same name the Hippocratic Oath and the Hippocratic Method, the ethical injunction on the one hand, the scientific insistence on the authority of observation and experience on the other.

The other sciences lag many centuries behind medicine in the ethical approach of their practitioners to their job; perhaps that may be because science in the past was practiced chiefly for its own sake as an intellectual interest, not as a vocation of practical and social value to mankind. It had, however, its own obligations of truthfulness and integrity, and there was a time when science and learning were accepted by civilized men as a natural bond between nations. That might still be so if scientists in all countries would, or perhaps if they could, insist on collaborating and on maintaining a common ethical standard for their calling. Failing that, one can foresee the time—if it be not on us already—when scientific discovery and invention may provide instead one of the chief stumbling blocks to international cooperation and the chief means for mutual destruction.

If standards of truthfulness, frankness, and integrity are relaxed either for political motives or for private ambition and gain; if fraud, dishonesty, and self-deception are not denounced; if mistakes are not honestly acknowl-

edged and corrected; if propaganda is accepted in place of fact; if the common prestige and good will of science are prostituted for base, sectional, or selfish purposes; if secrecy—or secretiveness—is accepted as a normal condition of scientific work; if age, prestige or authority, if race or nationality, is allowed to hinder freedom of intercourse or equality and interchange of ideas between scientists of honesty and good will anywhere in the world; if scientists allow themselves to be conscripted for the purposes of power politics; if, finally, there is widespread failure to recognize an unbreakable obligation—as it should be—that the benefits of scientific discovery must be regarded as a sacred trust for all mankind; if all these things fail, *then* science itself may become impossible as a vocation for free, honest, and decent men, while its exploitation for sectional gain or national aggrandizement may lead to conflict and destruction instead of cooperation and betterment.

It took hundreds of years for a common standard of medical ethics to emerge; we can hardly expect a common standard of scientific ethics to appear overnight. All kinds of difficulties will be evident, partly from political barriers and lack of freedom, partly from scientists themselves who are, many of them, I confess, pretty peculiar animals to steer in a common direction; but not least from the big bosses in all countries who look upon science as a purchasable commodity and scientists as "back-room boys" to be kept in their proper place. But the matter is urgent, and these are critical times.

There is no suggestion, at least I make none, that scientific men as such need feel obliged to spend their time in politics; indeed it is better to refrain from mixing questions of scientific ethics with political ideologies. Scientists

have their own specific contribution to make to public and international welfare, and their experience in natural science gives them no special authority to pronounce on other subjects. I hope that Dr. Bowman, who will speak later to you, will agree. Indeed, a dislike of misrepresentation and of compromise with the truth makes them usually, as I know, pretty inefficient politicians. Like other citizens they have their political rights and social duties; but those they exercise not as scientists but as citizens.

As scientists, however, they *have* the right, and indeed the bounden duty, to question and argue the nature of their own calling and its own special contribution—and its danger—to national and international welfare. They *should* feel an honorable and unbreakable obligation to keep the scientific faith of frankness, honesty, courage, and sincerity; to avoid secrecy, whenever possible, as a condition of their work; to treat all honest scientific men anywhere as coworkers in a common cause; not to exploit the common property of science for base or selfish ends; and to refuse conditions of employment or advancement, however attractive, that do not meet the ethical requirements of what could be—and should be—one of the most important common interests of mankind.

I would add a further duty, one of the most important and one about which many scientific men today feel very strongly, namely, to refuse to cooperate at all in tasks in which they, or their representatives, are not allowed a reasonable share—I say "reasonable," not dominant—a reasonable share or partnership in the responsibility of deciding on the purpose, or the policy, or the probable outcome of their work.

To a cynical observer of the recent behavior of *homo sapiens* these moral reflections may sound naïve. Perhaps

they are, and I admit that I often feel pretty skeptical myself about the outcome. But there seems to be no alternative; we scientists throughout the world must take the initiative in these matters, otherwise we and civilization may perish together. In England recently we have watched with admiration the example of strong and courageous initiative taken by certain American scientists in refusing to be coerced and conscripted against their conscience; the same determination exists elsewhere. As free men we are unwilling to be used as pawns in the game of international power politics, to consent in advance to the prostitution of science for secret purposes of which we may not approve.

The world at present is infected with partisanship, mistrust, and fear, with political conjuring and the enchantment of words and phrases; the common lot of mankind will never be raised by such maneuvers as these; a common motive of principle, morality, and cooperation is needed. No grandiose plan for conducting an international scientific orchestra is wanted; that would certainly play out of tune and out of time—if indeed it played at all! We must build patiently on what exists, we must tend and care for the living organism of those friendly international relations in science which we have inherited from the past.

On various occasions during the last year, I have been moved to urge similar conclusions, and recently I received unexpectedly, at the Royal Society, a beautiful and touching letter signed by fifty Rumanian scientists, among them officers and members of academies, and former Ministers, all of them unknown to me personally, which perhaps I may be allowed, with all humility in regard to its compliments, to read to you.

These people wrote me:

> We have been fortunate enough to learn accidentally, just now, the proposal you submitted concerning the fraternization of all men of science and a tight collaboration against any attempt to use science once more against humanity. We perfectly agree with you that the isolation of scientists has been a great mistake. Therefore words are lacking us to elogiate in due terms your noble initiative, to which we adhere with enthusiasm. We who belong to the smaller countries were most interested in such action long ago, but for reasons easy to understand, we would have missed any chance of success. Considering your high personality and the approval of the great nation to which you belong, we feel that your initiative will bear best results to the benefit of humanity. We wish you full success from all our hearts.

This letter shows how deeply concerned are our friends and colleagues in distant countries—many of them unknown friends—in the subject we are discussing today. They are isolated and conditions are hard, they feel impotent to influence world events, but they look with hope and confidence to us, particularly in America and England, to see that the common ideals for which science and learning have stood are not neglected or forgotten in the present crisis of human history. We know that the same feelings and hopes exist elsewhere, perhaps particularly in countries where they cannot be openly expressed, and we should be wanting in common wisdom as well as in humanity were we to fail to do whatever we can to bring those hopes to reality.

About six weeks ago there was issued to the world the report of a Board, set up under a committee appointed by the Secretary of State of the United States, on the International Control of Atomic Energy. That report is a

notable example of the mixture of hard common sense and practical idealism which is typical, if I may say so—and that is the opinion of all with whom I have discussed it here or in England—of America at its best. Its proposals, if adopted, might remove the nightmare of atomic warfare and so, in the end, prevent all major war, while allowing the fullest development of the beneficent effects of atomic energy by cooperative international action. The main requirement for the success of such proposals is a friendly and cooperative spirit between nations, together with good faith and a fixed determination at all costs to make the plan succeed.

In considering the subject of control in general we must remember that atomic explosions are not the only means by which a future aggressor might attempt to dominate the world: there are other weapons and forms of frightfulness, not so fully developed perhaps, or as yet tried out, which have similar terrifying prospects for the future in the hands of wicked men. Microbiologists, in fact, might make themselves as great international nuisances as physicists, and biochemists might be scarcely less objectionable.

The detailed proposals of the Board reporting on the control of atomic energy could have no direct application to the control of biological or biochemical warfare. May I quote, however the last sentence of the report? "In the long term there can be no international control and no international cooperation which does not presuppose an international community of knowledge." If that international community of knowledge can be achieved in nuclear physics, with its many applications, it is all the more likely that it can be achieved also in other branches of science, as in a large degree it has already been achieved in medicine. Science, in fact, could form a network of com-

mon interest, permeating and strengthening the whole fabric of human society.

What is needed then above all else is the inspiration of a great ideal, a common international interest, a common standard of ethical behavior, a common refusal to sacrifice or exploit a universal good for a temporary or sectional gain. We must have courage and endurance in refraining from selling reason to the forces of unreason. Those who fancy themselves as hard-boiled realists, as the "practical men" who practice the errors of their forefathers, may deride us and our principles. But the truest form of realism today is to recognize that human well-being, indeed the continued existence of human society, and any hope at all of reaching the promised land of healthy, orderly development, depend far more on improvements of morality, honesty, tolerance, reasonableness, and good faith than on inventions of machinery or organization. We scientists have provided mankind with the knowledge and the tools, physical and biological, either for mutual destruction and elimination, or for improvements in health, welfare, and happiness beyond all previous experience.

We have had a large part in producing a crisis in human history. Let us try to supply also, by our example, a common standard of ethical behavior and of courageous insistence on frankness and collaboration, so that mankind can decide, with his eyes open, which of those alternatives of destruction or well-being he will choose. It would be a sad epitaph indeed for the human race if extinction should result from scientific discovery applied and exploited without ethical control.

But people may say, "What's the good of all these moral reflections? Admitting the emergency, what positive action do you propose?" Form a new society? Draw up a

scientific charter? Set up another council under the United Nations? Organize a petition to mankind? Found an international brotherhood of scientists? Well, experience would lead one to expect rather little result from any of these, for argument would ensue as usual about membership, rules, formulas, voting, and procedure. Probably someone would veto the conclusions and those who wished to conscript science for their own ends would be clever enough to make quite sure that the main purposes were forgotten in the resulting scrimmage. The red-herring principle is highly effective, and most fights in the world are about words.

It has long been known that people cannot be made good or happy by Act of Parliament alone: positive individual effort and positive morality are required. I doubt indeed whether any action would be so effective now as merely to insist, day in and day out, that scientific men throughout the world should take solemn counsel with their consciences in private and in public about this matter. Of the result in any individual case one cannot be sure, and the scientific conscience itself would be outraged by a suggestion that all should be compelled, even if that were possible, to think alike. But I have little doubt that the opinion of the great majority would, within rather narrow limits, be about the same; for science is the most international of all interests, with a common tradition of freedom and tolerance, a common regard for honesty and fair dealing, a common skepticism of established authority, a common independence of spirit, a common dislike of propaganda, a common conviction of the absolute goodness and beauty of truth.

A code of ethics and behavior for scientific men could probably be drawn up to which the vast majority of them

would agree, at least if the red-herring principle were not imported to create confusion; but I should doubt the wisdom of drawing it up now, at any rate in detail, for it is all too easy to argue and fight about phrases and to forget the facts and principles behind them. The important thing is not a creed, "which except a man believe faithfully he cannot be saved." What matters is that scientific men should argue and discuss this subject of scientific ethics as one of infinite and urgent importance to themselves and to the world as a whole, with the same honesty, the same humility, and the same resolute regard for the facts as they show in their scientific work.

If they do, then something surely will crystallize out from their discussion, and I have faith enough in the goodness and wisdom of most scientific men to believe that the result on the whole will be good and wise. It may in the end be embodied in a new Hippocratic Oath; or it may be absorbed in trade-union rules for the scientific profession; or ethical behavior in science may just come to be accepted as an honorable obligation as unbreakable as that of accuracy and integrity. Having very little confidence myself in formal precept and written injunction, but much in the collective result of honest search (whether of nature or of conscience), I believe that the last outcome will be best.

The time is now urgent and the world situation brooks no delay. That is true, but scientific men, if they are to maintain the standards of their calling, would not tolerate the statement of a result before the investigation has taken place. To prescribe detailed rules of ethical conduct before the facts have been laid out and fully examined would savor rather of propaganda than of science. There is a vast difference between the religious spirit and formal theology:

dogmas and creeds may disagree but true religion is much the same throughout the world.

So it is with scientific ethics. There is no easy path to moral behavior: continual courageous and unselfish effort, together with frank discussion and humble searching of one's own conscience, alone can bring one through. A brotherhood indeed of scientific men already exists throughout the world. Let us build on it, not merely with observed facts and honest interpretation, but also with a sense of moral responsibility to each other for the good and not the ruin of mankind. That is one of the chief objects of this Forum. May it be achieved!

The Social Composition of Scientific Power

BY

DR. ISAIAH BOWMAN

President, Johns Hopkins University

Dr. Isaiah Bowman, *President*, The Jonns Hopkins University. World-famous geographer and educator; has led three scientific expeditions to South America. Director, American Geographical Society of New York, 1915–1935; president, International Geographical Union, 1931–1934. Chief territorial specialist, American Commission to Negotiate Peace, 1918–1919, and member of Paris Peace Conference. Member of Permanent International Commission, China and United States. Special adviser to Secretary of State; member of United States Delegation at Dumbarton Oaks and San Francisco conferences. Board member of Council on Foreign Relations and Woods Hole Oceanographic Society. Awarded Patron's Medal of Royal Geographic Society, Livingstone Medals of Royal Scottish and American Geographical Societies and Bonaparte-Wyse Medal of Paris Society.

The Social Composition of Scientific Power

EACH GENERATION REDISCOVERS THAT A MAN LEFT COMpletely to himself is enslaved by freedom. If he turns back to nature he becomes nature and deprives himself of the comforts, securities, and leisure that society affords. The primal desires include the compulsion to seek things beyond raw freedom and to create the social organisms of family and group.

Each step on that long road of seeking and of creating has diminished the "freedom" that marked the beginning, that is, freedom from restraint by others. Other kinds of freedom, and especially freedom to share in social advantages, are possible only when the narrow feral life is exchanged for the contractual community life.

During the past century we have moved into a time of complex servitudes or restraints upon freedom imposed by the larger and higher national "community" and its evolving policies. Science and increasing world population have wrought far-reaching social changes that have been raised to a new climax and given an unexpected orientation by two world wars.

For twenty-five years we have had a parallel upsurge of social ideas, many of them in sharp conflict with others, that are proving far more potent than machines—ideas that take account of the facts and conclusions of science

but also reach far beyond them into the confused and misty perspective of human desires. These new ideas affect our internal policies as profoundly as they affect our external or international relations. Here in the United States a national debt of $275 billion has struck its first blows and they are the blows of a giant, shattering in their effects. Men fear that all life will be enchained and individual freedom virtually lost even in this modern cradle of freedom.

Viewing our complex modern society, with its extreme forms of social control, men are bewildered and anxious as the sense of insecurity mounts alarmingly. Has organized life become so complex that it is getting out of hand? The gulfs between nations seem to be widening at the moment when faith in new instruments of peace is most needed. The object of the present effort in world organization is to achieve an ordered life of peace through agreement upon purposes, ideas, procedures, and judgments to displace a life of disorder and fear.

Totalitarianism strides upon the scene and offers to compose the troubles of the bewildered man. It assures him that he does not have to find the answer to complex questions through hard personal striving and thought. He need not define his aims or set standards of personal character. He need have no faith in man's historic endeavor to secure a better society by developing better individuals. In fact he can easily deceive himself and suppose that he is creating a new and beautiful social order when he is really destroying the foundation of all lasting creations, personal integrity.

Destruction is the outcome of the doctrine of the easy road. The first law of totalitarianism, whatever its brand, is to destroy character. The second law is to destroy indi-

vidual worth and identity. The third law is to destroy, through falsehood, faith in the leadership of any opposition. We have seen most of Europe corroded by these doctrines and confused by these techniques.

When life becomes both hazardous and puzzling, men are likely to surrender to simplicities. Especially is this likely to happen if security is promised along with simplicity. Only one faith is then needed, faith in a promise whose voucher is violence. At a stroke the lessons of man's long creative experiment in social living are bypassed by stigmatizing them as the record of capitalism, a charge that some find easy to believe because something is wrong and clearly something is the cause of it! Simple minds are captured by the suave doctrines of simplicity, especially when their applications are far away and within a society totally unlike our own. These are among the age-old allurements of Utopia, where practical troubles never arise. Hundreds of cults in the United States testify to the strength of the *doctrine of simplicity* among people who have given up the struggle of thinking through their difficulties and earning their salvation.

The moment a man succumbs to the persuasions of totalitarianism he becomes malleable. Abandoning the doctrine of individual integrity, he turns to the leadership principle. Men without established spiritual homes will run toward any sheltering grotto in time of doubt or storm. We are at this appalling juncture today in a world afflicted with a high fever of unrest.

Believe me, ladies and gentlemen, there is much more to this than science or machines. The heart of the business is a choice of philosophies which affects, if it does not determine the answers to, all questions about science and machines. We must settle the hard questions of purpose

and individual effort and national and international programs in their *togetherness* before we can hope to find assurances that will help stabilize our distraught world.

We must all be social scientists first or, by placing power in the service of corroding ideas, we may end by destroying the creative human spirit that is responsible, in the millennia of past striving, for what we call civilization. That is to say, civilization needs many-faceted manhood, while totalitarianism begins by destroying manhood. That each man is unique is, quoting Charles Morgan, "the central fact and miracle of creation and the denial of it is the central blasphemy."

Today we are celebrating the centennial of the birth of George Westinghouse, a great engineer, an applier of scientific discovery. Engineering is nothing apart from human benefit. It is or should be one of our leading social sciences. The tools and methods of science acquire nobility only if the social effects of scientific and engineering endeavor are acceptable in terms of the good life, which means *earned access to goodness and self-disciplined life.* This is implicit in the title of the program "Science and Civilization," on which we are speaking today.

There is a further reason for opening my address on the note of broad human motivation. When scientists foregather they are disposed to praise science. As one of the breed I know how easy it is to point to social benefits that science has bestowed or made possible. I remember the large areas of spiritual freedom that have been won by scientists and by laymen walking in the light of science, as opposed to the fog and darkness of superstition.

It is always tempting to turn to brilliant examples of beneficent scientific experience, to the beginnings of rational thought in this and that sector of action, to men

who found verifiable reality where fantasy or superstition had formerly held sway. The major achievements of science have in them the stuff of poetry. Science is not confined to critical processes. Intuition plays its powerful part. Some discoveries have been stumbled upon by accident. Some are the product of vast inductions; others are deduced from fragments. We guard intellectual and political freedom chiefly because it releases that wide-ranging mental and spiritual energy upon which discovery and creation thrive best.

But we cannot stop with a recital of the glories of science. There is in us today an urge to question civilization, including our American civilization, its ends and its means. On this occasion, therefore, I choose to talk mainly about civilization rather than science.

There are a few places in the world where men of former times thought they had reached a state of civilization and spoke in terms that are of deep interest to us today. There was limited use and still more limited recognition of science as an element in social living in those earlier times and places. The Greek examples are familiar to you and I will not dwell on them. I take, rather, the case of Italy in the fourteenth and fifteenth centuries, a time nearer our own, yet well before the dawn of modern geographical discovery and ensuing world trade and centuries before the modern scientific age.

There were five principal centers of political and military power in that period: Naples, Venice, Florence, Milan, and the Papal States. Their rivalries were the central fact of the political life of the period. But in the field of associative living there was growing interest in experiment and initiative. Self-supporting trade guilds were organized and gained in civic power. City individual-

ism was coupled with economic prosperity. An astonishing rise in creative power marked the period. Improved agriculture and weaving, far-reaching trade, and rational management of property were among the credits of the age. Child labor in dangerous trades was forbidden. Ships could not be dangerously overloaded. There was deep general interest in special talents in the arts. Justice was raised to a higher plane of humanity.

Why this prolonged creative period produced such cardinal results is one of the mysteries of time. Men learned for a while, in a fragmentary but illuminating way, what it was to be civilized in the sense of creating and enjoying things of enduring beauty and also foreshadowing, in spite of low political standards, a more liberal political system—in sum, we have here, as Durand and Baron have emphasized, a prototype of the modern pattern of things.

Clearly civilization means something that science can support and amplify, but, equally clearly, science played but a small part in what was once an acceptable civilization. We think that civilization is advanced by the ameliorations of applied science, but civilization is also good spirit, applied conscience, fairness as interpreted by incorruptible courts, appreciation of beauty, the exercise of tact, the display of good manners, the social expression of the virtues of men, and, in America (as an ideal at least), a dynamic political force that gives practical effect to the informed will of the majority. It does not mean blind power, fortified by science, or power cunningly contrived to keep men bound to a system of work and government that makes the individual the subservient tool of a small group at the top.

Civilization as a word and an idea became popular in

France about a generation before the French Revolution. This, too, was before the modern scientific age. There it meant worldliness, a cultivated personality, a graceful manner, and correct speech, an ideal of gracious living. Far behind in the reaches of time lay the centuries when the church had substituted hope for despair as Roman civilization lay in ruins. Church leadership was then able to provide a comforting moral authority in contrast to the decadent standards of worldliness all about it. The new French concept of civilization took a view of things less severe than the church: gaiety need not be excluded and the spirit of Christianity need not forever be adapted exclusively to life in the rude catacombs that once sheltered its ill-clad, ill-used, and humble followers.

How are we to define civilization today? Have we an agreed set of criteria? Do these criteria match those of Italy in the fourteenth and fifteenth centuries or France in the eighteenth century? About fifteen years ago a table was published which showed the relative "cultural rank," or "general civilization" of our forty-eight states. The criteria that were selected relate chiefly to measurable items—school attendance, farm tenancy, telephones, lynchings, strength of evangelical churches, and gasoline consumption. Only by inference do most of these items relate to taste, appreciation, manners, and creative intellectual power in the arts. They indicate rather the *degree of access to the material means of culture* and public willingness to pay for the means. They gave limited attention to culture as *practice.*

Without extending our comparisons we may conclude that an acceptable yardstick of present-day culture has not yet been found. Moralists agree that if happiness is sought in *things* only, or in money or power, the man in

search of them is culturally sick. Yet most people seem to strive for the items on the proscribed list.

To one man culture signifies better social organization, to another the wider influence of taste in art, to a third the rationalities of science. We devalue society and civilization if we think only in terms of efficiency or things or regimentation from without, the great creative eras in the world's history being the eras of free growth in disciplined or practiced striving urged on by "rivalry in excellence."

Something is lacking in a study of man that is limited to scientific causes and origins only. The thing that is lacking is *the present-day relationship of the parts of society*, or that social *togetherness* in which men have discovered freedoms denied to them in the primitive state. A practical working relationship on the higher levels of organization at times becomes socially more important than a scientist's enthusiasm about origins. Causes and origins are important as scientific discovery in and of themselves, but they are important as social discovery only when we have identified their functional relationship.

One of the most active of the forces that affect the relationship of men to men, village to village, nation to nation, is conscience, an ethical quality to which men give at least lip service in establishing peaceful relationships. It is a force in self-discipline. One of its widest extensions was made in the abolition of slavery. Documentation of these statements in treaties, conventions, proclamations, and wars provides an imposing array of evidence of the efforts of self-discipline guided by conscience. Another force is standard of living, which again expresses a humanitarian code with respect to a fair division of the privileges of access to the enjoyments and securities of life. While we

cannot weigh conscience in the scales of science, we can weigh it in the scales of human conduct. It affects all levels of organization from top to bottom. It is in the preambles of the most important treaties. It is the invocations in the opening paragraphs of the Charter of the United Nations.

At the highest levels of organization and of statesmanship, whether in science or of states, a further complicating factor makes its appearance, namely, *changes* in relationships. A change of political position in America means a change in our relationships with all the rest of the world, either in kind or in degree. This is one of the central facts in human affairs. It is what gives social meaning to origins in the field of discovery of useful knowledge and to the spread of the materials or resources that sustain and amplify life. Unpredictable life keeps bursting through the crust that forms over the meanings and over the words of social establishment.

Among the effects and the agents of change in the past century we identify power. It is no service to useful political thinking or social thinking to stop with vast dreams of brotherhood as the basis of policy and ignore the existence of power, which science and engineering have now extended to Protean dimensions. We might as well ignore gravity as to ignore the realities of power in international politics. Those realities are not determined by the United States alone but by the play of feeling and judgment between nations with different objects, different backgrounds, and different outlooks.

To understand *our* situation requires us to try to understand the situations of sixty other countries. A harmony of purposes among the nations that live in the house of mankind is impossible if power is misused. But

"misuse" will be determined on different grounds by different social systems and political systems. Might could be on the wrong side. How can we be sure that we are joining might and justice?

Science comes into the picture because of the power of the laboratory. With sharp realization of that power, some scientists during the past half year have jumped into the arena of unaccustomed political debate and dashed off the answers to questions that men have been struggling with for thousands of years. Without realizing it, they have abandoned scientific method for polemics. Their distinguished discoveries have been made by forms of intellectual attack that have little or no relevance to the political questions of the hour.

It is for these reasons that we desire to examine the relation of science to that form of social composition called international politics. If this seems too much like juggling —tossing two worlds into the air at once—it is no more than what all statesmen are obliged to do.

There is an assumption that the acknowledged virtues of scientific method are applied by a scientist when he enters the field of political debate. This is clearly not true. A scientist is accustomed to verifying a result by repeating an experiment or by extending critical field observations.

In politics we can only speculate but never prove what things might be like now if they had been different at an earlier time. We cannot fight over again the Battle of Waterloo and make Napoleon the victor. We cannot restore the status of 1914 and find out whether a sharper British warning to Germany might have *prevented* the First World War or, contrariwise, might be set down by future historians as the immediate *cause* of the war. The distinction must be made between the experimental and

field methods and results of science and what a scientist says about things that are inherently doubtful and quite certainly not capable of duplication.

The language of a scientist when discussing political affairs commonly has a misleading quality. Accustomed to thinking in logical terms he advances from premise to conclusion over what appears to be solid ground. When we come to examine his argument critically we often find two forms of weakness. One is the weakness of the basic *assumption* and the other is the weakness in his *choice of social process* to accomplish the result.

If a scientist happens to be one of that small number who favor communism, the assumption on which he proceeds is that we should act so as to bring about communism because communism by definition will solve all social problems. This weakness the occasional scientist shares with some religious teachers, who argue clearly up to the point where they are face to face with the main difficulty, namely, how to displace military conflicts of purpose and program in the international field with the harmonies of peace that we all desire. Confronting the supreme final difficulty, the religious preacher points out that if all men were to worship God and follow the teachings of Christ, our international difficulties would disappear. This led in 1944–1945 to the advocacy, by some, of a so-called "Christian peace."

The phrase "a Christian peace" is at first sight plausible. But how is a Christian peace to be made with a Buddhist or a Moslem or a Communist? By force or by persuasion? How is one to do in six months of international conference what Christian missionary work has failed to do in 1900 years? The common denominator of peace, one concludes, is not religion. It is in a group of things more

general than that. It is in the application of a universal conscience (yet to be developed generally), combined with a universal sense of fairness (yet to be agreed upon), and a conviction (yet to be accepted), that "the common mass of plain sense (of fairness) is the great administrative agency of the world." One concludes that peace for this diversified world cannot be written in terms of rival religious doctrines or beliefs, and that peace can be imposed upon such rival groups only at the cost of war.

The recent report of the Federal Council of Churches of Christ in America exhorts men to dedicate themselves to "the world-wide achievement of man's individual freedom, under God, to think, to believe, and to act responsibly according to the dictates of his own conscience." Men see hope, the report asserts, in the growing conviction "that peoples, not free, must be helped to self-government" and that science can "lighten the burden of ignorance, disease, and poverty and thus relieve the tensions which conduce to war." Among the causes of tension that the Federal Council of Churches noted are the diversities of the world and particularly the differences between the Soviet Union and the Western democracies.

Thus the report frankly runs toward political action—"the practice of our belief has achieved, to a remarkable degree, religious and political freedom," says the report. Specific recommendations are made respecting trusteeship. Boundaries are referred to and reference is made to "the natural long-time aspirations of inhabitants" (with nothing said as to the conflict of aspirations!).

Moral transformation is the Christian keynote and the warning (and here the refractory nature of man confronts us with age-old difficulties). "Brotherhood is now the spiritual imperative of survival," says the report. The pro-

jection of Christian principles into United Nations *operations* is declared to be an essential of the Christian program.

It sums up to this: there should be a *peace of conditions*, the best we can get, in my belief, and *after* that, there should be resumed the centuries of Christian striving for the betterment of these conditions. There is to be also, in such a plan, we hope, Moslem striving for the same agreed ends, and Hindu striving. Spiritual doctrine is thus removed from the field of charter making to the field of changing and flexible agreement upon social legislation under the charter. Expressing one of the great hungers of mankind, religion has a chief role to play in making and keeping the peace. It is of the utmost importance, however, to see clearly that it is no panacea and that one religion cannot transform the world at a stroke.

The words of idealism are easy to write. They are hard to define and apply regionally. Freedom, for example, is not the Declaration of Independence plus an American way of living. It is not just a constitution, a secret ballot, and a threefold division of governmental powers. The tribal organizations of Arabia, to take an illustration, want none of these things. A charter of freedom cannot stop with the acceptance of the doctrine of "freedom to think, to publish, to assemble, to worship."

By themselves these articles of freedom are meaningless. A man who is ignorant is not free and we therefore *compel* elementary-school attendance in America to make freedom available generally. A man receiving 1,000 calories of food for 12 hours of hard manual work per day with insecure tenure of job is not free. We therefore limit hours of work and strive to establish a proper standard of nutrition, that is, *one which our consciences approve.* And public conscience is what creates and supports the power

of the law. We compel by law the observance of the conditions without which no man is "free."

The stable world peace we all want, in the face of these diversities, is a peace of *conditions upon which we can agree as fair and right and without coercion except under prearranged and pre-agreed circumstances.* It is the largest number of conditions possible to assure the grand object in view, which is cooperation in keeping the peace while attacking the root causes of war. It is a web of conditions, each strand in place, and not just a hit-and-miss selection of conditions. If "no one can foresee the future—not even those who make it," the conditions of international living must be avowedly subject to change, and the changes must be by agreement, for disagreement is war, either declared or potential. With the best will in the world, the conditions of peace will fit into an acceptable pattern only with extreme difficulty.

No one denies the advantages or even the necessity of "one world." The practical way of achieving it is quite another matter. The San Francisco charter, incredible as it may seem on theoretical grounds, found a common denominator of generalization about war and peace in the words of a text and agreed upon a set of conditions. The real difficulty with which United Nations is now confronted is to find a common denominator on the working level, when we are required "to think in things, not words," as Justice Holmes put it, that is, to think about and agree upon and arrange for contradictory definitions, diverse cultures, and mutually repellant social systems. That is where the trusteeship problem raised its head. A great moral principle had to be ventured.

Time had germinated and the war had nourished a seed of conscience that grew into a deep conviction. Western

ideals confronted Western practices on distant political frontiers. Gandhi, Nehru, and Jinnah all had an English education in part. Moved by the impending horrors and sacrifices of war, our leaders took pledges of idealistic consecration.

The spirit of the hour called for noble sentiments, plain expression. Thus spoke Lincoln in 1861 when men were asking, what is the war for? Lincoln said that the war was to preserve the Union and also lift burdens from the shoulders of all men and give everyone a fair chance in the race of life. Thus spoke Woodrow Wilson in the Fourteen Points and in his various speeches, and Roosevelt in the Atlantic Charter and the Four Freedoms. In the crucial days of war and self-examination, men's spirits require idealism as the body requires food. Each man must see and feel a lofty world meaning in his personal sacrifice.

On both the near and the far horizons of human conflict today one observes the meeting of irreconcilable programs and ideologies. Clear before us are the growing opportunities for that disintegration of personality and society that totalitarianism effects before democratic integration has begun in the confusion following war. Representative government among politically inexperienced people is a slow growth. No wonder that the world collision of ideological systems focuses also at the trusteeship council table. Alas, that dependent peoples are now buffeted in the struggle of social and political systems whose centers are so remote and powerful.

The political agenda of the citizen must include these contradictions of principles and practices, these complexities that spring up when an idealized program is reduced to cases. One eminent scientist has argued that "co-operative research" by historians, economists, and phil-

ologists is needed for "an intelligent peace" and that the "failure" of the London Conference "revealed dramatically what a poor research job had been done."

From a long experience I may assert with confidence that no sharper divisions of opinions or of counsels of action are to be found among politicians than among researchers. Among research men the value judgments, political and social prejudices, or assumptions, and even secret loyalties and margins of error, are no less real and determinative than those of any other class of men dealing with social forces. "How do you want to live?" is the name of a very broad street! It is a street that may lead far from the laboratory, the repeatable experiment, and "right reason."

Life, like war, is a series of surprises. Today not a few consider the atom bomb as the core of foreign relations. In the time of James I, when the interests of church and state were intermingled and states were the champions of specific faiths, foreign politics was in effect a branch of religion. The architects of Versailles in 1919 have been condemned for a fragmentation of Central Europe. Well, conversely the treaty of Vienna (1815) was condemned because a number of virile nationalities—notably Czechs, Poles, and Serbs—were placed under hated masters. Within broad limits the Treaty of Vienna defined the then prevailing idea of a Europe of powerful master states.

There are no universal laws in statecraft, no timeless principles, no logic outside the natures of men. As the picture changes, philosophies change. The heated conflicts of three hundred years ago seem trivial. Government, said Ramsey MacDonald in the troubled days of 1931, has become an ambulance always hurrying to the scene of the

latest disaster. There are no finalities anywhere in the field of public action.

When men seek finality they lose sight of a fact of life as all-embracing as the theory of relativity, namely, that the combinations of power and ideas and their decisive effects are constantly and inevitably shifting. While paying lip service to the fact of changing combinations, most men refuse to admit it in practice as they cynically reject all hope of betterment or seek it naïvely in one universal law or in a so-called "world government."

The human drama is due in large part to the eternal conflict between the inevitability of change and the endless effort of society to establish points of stability for longer or shorter periods of time. The world hungers for stability and peace, while the facts of life drive men inevitably toward change and strife. We have never succeeded in striking a balance between change-not-too-swift and fixity-not-too-long.

In the fifty years before the First World War, even thinking men, the best of them, mistook cities and machines and literacy for civilization. When life seemed most secure and full, one of the greatest slaughters in history was impending. Humanity will probably forever dream of a peacefully united world. It will have it only by superhuman striving in a world where but a handful, among the many who sit in the seats of power, share the dream. We shall not find peace in formulas or in simplicities or in a world religion or in a world government. The world is still like that of Louis XIV, of which H. A. L. Fisher has said, "the language of the guns was always ready to repair the silence of the law."

Men say that the idea of world cooperation will surely work now because the swift communications of science

have so obviously brought the world together. Alas, that our togetherness is an affair of copper wire, airplanes for the few, and radio for the many for entertainment and propaganda, rather than an affair of recognized universals of spirit and ideals. Men stubbornly deny the hard realities of diversity. It is so much easier to dream simplicities! Our views are no less bounded because we travel around the world swifty and talk to it on the instant. The spiritual boundaries persist, however open the geographical highways.

Before us today is the profoundly important fact that only two great powers have the opportunity to continue in the pioneering stage of scientific, industrial, and trade expansion. They are the Soviet Union and the United States. Every coming event in the international political field will be colored by this stupendous fact. Only these two have the vast depths of partly developed resources, the population growths, the technical passion, and the majestic outlook that numbers and power imply.

The far horizons of American and Soviet opportunity and accomplishment are in sharp contrast to the conditions of other states. While America is now in the lead, there is little to choose between them as to future power if we balance the factors one by one, with a single exception. We think that the ultimate loyalties of men are best called out by a system of free enterprise. The Soviet Union believes in a contrary view, and we ask whether the cry of "encirclement" therefore is an artificial one in the designs of the Soviet leaders, who thus prolong among their people the fear of war? Is the cohesive power of fear among the Russian people the offset to the internally divisive effects of the proclaimed conditions of a free peace?

Yet there are reasons why our hopes for an acceptable world peace are not altogether visionary. There is a new high level of publicized opinion in the world. The outcome of its play may be the striking of a fresh balance in the broad field of conciliation. As we analyze the points of difficulty, bases of hope appear, among which we take time to mention but four:

1. The designs of totalitarianism aside, the Western world has a clearer idea than ever of what is right and fair and of what fairness costs in perpetual sacrifice. The United States government, with full popular support this time, took the initiative in seeking peace by world agreement, intensifying its effort from October, 1943, to June, 1945, and persisting until a world charter was accepted.
2. Never before in history have peoples and governments so generally tried to settle international difficulties by debating the issues in an international forum in open view. If the exchanges are harsh, the facts of life are harsh also.
3. Science has made possible vast ameliorations in man's lot everywhere, and the end is not yet in view. The merest catalogue of possibilities would be as long as this paper. With the benefits of such ameliorations more widely extended we may reasonably hope for lessening tension.
4. We are at last seeking the causes of international conflict in the deeper natures of men and institutions and practices and relationships, rather than in formulas. We see that knowledge of ultimate causes and changing causes must displace ignorance, the determined and the determinant often changing places.

And finally, when the story is told and the balance struck, it is *faith* in the progress of man, in the ultimate triumph of a practical humanitarianism, that sustains effort. Not the neutrons but the social impact is important, and men are trying to make the impact manageable in terms of conscience and fairness. A man is a humane composition, hopefully a balance of spiritual forces, not always and everywhere a devising brute with a thunderbolt in his hands. Totalitarianism has heightened our appreciation of the things of the spirit, of idea as power. Humanitarianism is the sworn enemy of totalitarianism, wearing whatever mask it may. Totalitarianism attacks the very citadel of personality, rejects standards, pulls lown character, explicitly confuses issues, destroys faith n the individual.

Facing the raw facts of today's world we see a special role for science. If it is not yet in the area of free discussion the world around, its tendency is unremittingly international. Discussion under free conditions will help reduce the most refractory difficulties. It has been said that government by public discussion "broke the bond of ages and set free the originality of mankind." Parliaments rather than dictators, free speech rather than "party line," rising standards of living to which applied science contributes powerfully, a striving for peace rather than a striving for confusion supported by fear—these are some of the building blocks of our future "good life." Among the agencies are all forms of learning, including science. "There is no acceptable currency between nations that distrust one another," says Charles Morgan, "except genius and goodness, the gold and the silver. All else is propaganda, the devil's dross, which will buy none but fools."

Commentary

DR. ROBERT E. DOHERTY

President, Carnegie Institute of Technology

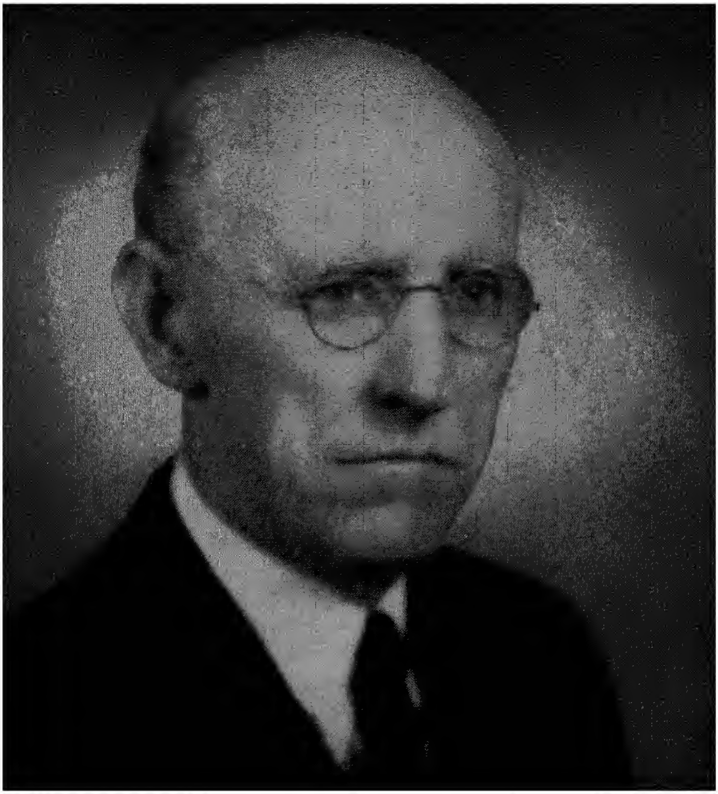
If I have understood the speakers, they concur in one important conclusion—that conclusion is hope that we can realize our dream of a world of peace, plenty, and health, but only at a high price. It will be the price of a long spiritual and intellectual struggle, which must begin now. We must learn, step by step, how to place ethical principles and moral values before savage instincts and how, through use of science, to organize a world social structure that will be dynamically stable and can adjust itself to inevitable change.

Man must struggle, as Dr. Hill says, from the valley of unreason to the valley of reason; and scientists, from a science that has insisted only on the authority of observation and experience to a science that, like the medical profession, will insist as well upon ethical standards. Scientists, in other words, must establish a tradition of moral obligation as well as of scientific method.

Dr. Bowman sees hope in humanity's dream of a peacefully united world, not in the easy and simple process of surrender to totalitarianism, but in the struggle of "earning salvation." In this struggle he sees the necessity, not only of understanding the causes and origins of social forces and institutions, but also of adding a new effort: to identify and, under the guide of conscience and moral purpose, actually to establish the proper relationship among

these factors—or, as he puts it, to establish national and international programs in their "togetherness."

Then one sees in both of these papers emphasis upon the time element. Now, when men's minds the world over have been lifted through the forces of total war to perhaps a higher moral plane than ever before, when threats of misuse of atomic energy and biological warfare hang over us menacingly, is the critical time to launch this struggle. Let me express our hope that this conference may have made a contribution to this end.



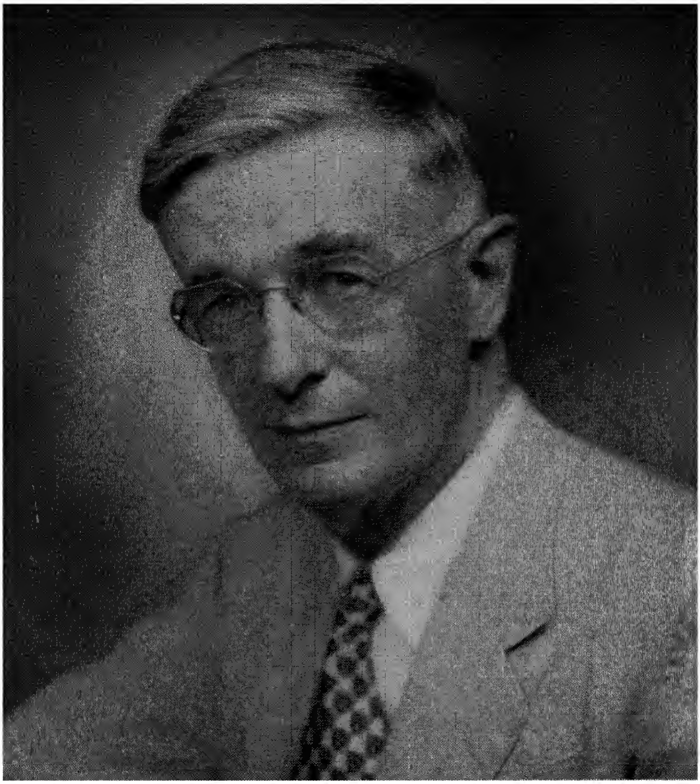
Dr. Robert E. Doherty, *President*, Carnegie Institute of Technology. Noted educator, served during war as chairman of Consultative Committee on Engineering, War Manpower Commission; as expert in Army Specialized Training Division, War Department Services of Supply; and as member of National Advisory Committee on Engineering, Science, and Management War Training, and of Civilian Advisory Council to Military Training Service of Ordnance Department. Member of Production Planning Board of Office of Production Management, National Advisory Committee on Aeronautics, and Engineers Council for Professional Development. Former dean of Yale's School of Engineering, past president of Society for Promotion of Engineering Education. Awarded Lamme Medal by American Institute of Electrical Engineers.

Planning in Science

BY

DR. VANNEVAR BUSH

Director, Office of Scientific Research and Development
President, Carnegie Institution of Washington



Dr. Vannevar Bush, *Director*, Office of Scientific Research and Development; president, Carnegie Institution of Washington. Chief of the United States wartime scientific high command. His early business career began with test department of General Electric. From 1919 to 1938, professor, dean of engineering, and vice-president, Massachusetts Institute of Technology. Since 1939, president, Carnegie Institution. Awarded Levy Medal of Franklin Institute, 1928; Lamme Medal, 1935; Research Corporation Award, 1939; Ballou Medal, Tufts College, 1941; Edison Medal and Holley Medal, 1943; Gold Medal, National Institute of Social Sciences; Distinguished Service Medal, Roosevelt Memorial Association; Hartley Medal of National Academy of Sciences, 1945. Former chairman, National Advisory Committee for Aeronautics and National Defense Research Committee.

Planning in Science

THE SUBJECT "PLANNING IN SCIENCE" IS INDEED A broad one and will require narrowing down by definition if our consideration of it is to be at all effective. It is quite proper to relate the two terms "planning" and "science," for science is organized knowledge, and planning is organizing. Between science and the idea of planning there is hence an inherent linkage. But we cannot talk about planning in science as a thing by itself. Science does not exist or operate in a vacuum, and, for discussion to be useful, planning in science must be regarded as a part of the planning that is basic to proper functioning of the whole complex of industry, commerce, education, social action, and government that goes to make up the United States.

This perspective in viewing science and the planning of science is far more necessary now than ever before. A half century ago, it might have been practicable to discuss the planning of science by itself and apart from these other considerations. But now, science has moved from the wings, has come to a position in the center of the national —even of the international—stage. It plays a leading role in the human drama, and, what is more important, it is recognized as playing that leading role.

In this drama, however, science does not hold the center of the stage alone. There is no prima donna in this drama, and no prima donna is wanted. Science is sharing

the center of the stage, sharing it with other players whose roles contribute as much and maybe more to the development of the action. For it is comparative contribution that determines nearness to the center.

Up to the years immediately before the Second World War, the contributions of science to American life had been very great indeed—directly through medicine and allied avenues and indirectly through the provision of a myriad devices, instruments, machines to facilitate the business of living, to speed transportation and communication, to multiply the power of man's hand and simplify the work of his mind, and to provide him with recreation, amusement, and instruction.

These latter contributions of science I have called "indirect," because the fundamental scientific knowledge incorporated in them is brought to general utility through the collaboration—sometimes the intermediation—of technology, of engineering, of industry, of finance, and in many ways of government through suitable legislation and through other action. All in all, these contributions, direct and indirect, which science made in the century preceding what we trust was the last great war are of themselves sufficient reason for the share that science now has in the center of our national life.

But in the past six years, however, a change or advance has occurred in the activities of science—a change of profound importance both for the role of science in our life and for the relation of the planning of science to other aspects of our general planning. This has taken two forms.

One may be illustrated by the way in which, applying various techniques of mathematical analysis to combat problems, physicists, mathematicians, and engineers, working in what were known as operations analysis sec-

tions attached to the armed services, proved time and again the rigor and the value to be had from using on military and strategic problems certain methods and procedures developed in the past for the convenience of scientists and engineers in working on laboratory and field problems.

Substantially, the operations analysts working with the Army and the Navy demonstrated that systems hitherto used by scientists for finding out about the probable distribution of molecules in a crystal or about the phenomena of electricity could be powerful aids in determining how to seek out an enemy submarine or in ascertaining the bomber formation most desirable from the point of view of defense. More than that, they demonstrated that the best, if not the only, individuals to carry over the application of these methods to strange fields were they themselves—the scientists and engineers familiar with the methods at first hand, though at the outset entirely ignorant of the new problems to which the methods were to be applied.

Let us look now at the other side of this medal. In certain parts of the utilization of science during the past six years to supply instruments of war, another phenomenon of comparable significance occurred. It took place when the instrument or other product of scientific investigation was intrinsically so complex and delicate that it either required an utterly new process of manufacture or demanded in manufacture quality and other control procedures of such intricacy and rigorousness as to exceed even the world-leading capabilities of American industry in that regard.

In some parts of our extensive radar development, in some stages of the development of atomic explosives, and

notably in the development of the proximity fuze, situations arose in which it was necessary for the scientists and engineers themselves to carry the undertaking beyond the laboratory and design stages, beyond the pilot-production stage, and to stay with it throughout mass production.

In the history of the proximity fuze especially, extreme importance attaches to the fact that the scientists who mastered this seemingly impossible task of initial design and development went on from there—because only they could do so—and not merely supervised but actually controlled production of the fuze at every stage from assembly of basic components all the way through to final delivery of the finished product. Thus was an older situation reversed, and production became a function of research rather than research a function of production.

In the first of these illustrations—that from operations analysis—we have scientists and engineers successfully bringing their methods to bear on the solution of specific problems foreign both to the methods and to the men applying them. In the second illustration—from the production of radar, the atomic explosives, and the proximity fuze—we have them successfully learning and putting into operation methods and techniques essentially foreign to them but rendered necessary by the dimensions of a problem posed by their work.

Call the first, successful extrapolation of some of the methods of science to problems at first considered outside their range. Call the second, the successful translation of scientists and engineers into specialists of a sort in production and industrial techniques. When we bring the matter down to these terms, doubtless it can be shown that both phenomena have occurred elsewhere and earlier than the instances I give. Nor were the scientists and engineers the

only ones to undertake new and strange responsibilities; industrialists and many others did similar pioneering. Even so, a markedly significant change in the activities of science was made plain by the events I have singled out from our war experience.

That change is a change in the nature of the contribution that science makes to our life as a whole, the contribution that has brought science to share the center of the stage. I think it is a change that will on the whole strengthen and confirm the right of science to share in that center and which will place upon scientists new, difficult, and interesting responsibilities.

Essentially, what these phenomena suggest to me is that the contribution of science to our life is in a fair way to become more and more a direct intellectual contribution. This is not in any sense to deny that the material things that industry has supplied us as a result of scientific endeavor grow originally out of intellectual effort.

But there is a difference between them and, say, medicine as the avenue by which science becomes a part of the life of the individual and of the nation. In medicine, in surgery, the organized knowledge and the controlled, planned competence of a scientifically trained individual are brought to bear directly on the well-being of the individual citizen, either in the treatment of one man's ailment or in the concerted checking and prevention of mass ailments, as in epidemic control. The contribution in either case is primarily intellectual and is made with little if any intermediation by other individuals or agencies, being rather the application of an appropriate intellectual ability to a necessity for which it is inherently designed.

But, as we have seen in the wartime examples I have cited, such intellectual ability can be, and very effectively

has been, applied to necessities of other kinds as well, to the solution of problems and the resolution of difficulties for which it was not intrinsically designed. I believe that this situation will and must continue, in fact, that it will and must be greatly extended in the years to come.

Do not mistake me, however, as blandly joining the chorus which is bewitched by the magic of the word "science" and sings an ill-considered and often cloying paean of praise to something summarily referred to as "the scientific method." I am decidedly not one of those who speak of the scientific method as a firm and clearly defined concept and who regard it as a mystical panacea immediately applicable to any trouble and immediately productive of complete cure. Of course there is a system of approach to specific problems that we know as the scientific method—an orderly sequence of hypothesis and analysis, which by a series of approximations and tests culminates in a practicable theory of operation. But to give this name of "scientific method" to mental operations involving no more than the use of common sense, or indeed to operations that are no more than rigorous logical thinking, is a mistake.

I therefore wish not to be taken as joining those who facilely argue that all we need to do to settle any difficulty is apply the scientific method to it. Nor do I wish to imply that the greater frequency which I foresee for direct intellectual contribution by scientists to our national life will consist principally in attempts to carry over into public forums, legislative committee rooms, and industrial plants a specialized technique of thinking admittedly very effective but admittedly also best suited to the laboratory and the study.

I think that we must consider the increasing direct

intellectual contributions of science in more down-to-earth terms. They will be made because the necessity for scientists to take a direct part in affairs outside their main professional concern is sure to increase in the future—a fact not altogether pleasant when we remember how easy it is for a scientist to be converted into an ex-scientist by too much outside preoccupation. These intellectual contributions, I believe, will consist primarily in an attitude toward factual data, in the effort at sharp and specific definition, in the endeavor, whatever the issue under consideration, to clear out extraneous side issues and focus attention and effort on the nub of the problem.

These things are fundamental in the planning that scientists do in their own work, and I think we can agree that that planning has been pretty generally effective. They can be of equal value in other kinds of planning, particularly because much of our national planning in the future will necessarily be concerned with problems growing out of the work of science. It will be profitable for us at this point to review a few of these.

We must consider planning by and for the United States in a world at peace yet still shaken by the worst war in history. It is a world perplexed by the vast perils, responsibilities, and opportunities produced by our mastery of atomic energy. It is out of balance economically and socially because of the destruction of great industrial areas and the disruption of many of the centers of civilization. But it is a world that has at least an approach to insurance against the disaster of fear, in the operating fact of the United Nations and the faith in the basic good will of men that has made UN possible.

It is important that we recognize constantly, too, that this is a smaller world than we have known before—not

merely smaller in the physical facts of space and time about which so much has been said, but smaller in the number of Great Powers available and able to administer and advance the affairs of mankind.

In moral force and significance, there are five Great Powers effective in the world today. In material resources, however, two Great Powers are dominant, by the fortunes of war. Their three colleagues in the Big Five, because of the unstinted devotion with which they gave everything they had in material, in machines, in treasure, in men, to beat down aggression, came out of the struggle greater than ever in honor but weakened and depleted in material strength for the arduous years ahead. For the good of the world and for the development of peace and plenty under the aegis of the United Nations, it is clear that the balance must be redressed.

The United States has realized that it must plan to give of its substance and strength in order to aid its moral peers to rebuild their shattered cities, to restore their industrial capacity, to repair the ravages inflicted on their people by hunger, disease, and disaster. Only thus can the commerce of peace be restored. More important, only thus can the full effectiveness of the United Nations be attained, for, in order to establish once and for all the mutual confidence among nations that is vital to international security, there must be individual confidence based on strength.

Moreover, for the United Nations to be able to act, it must itself have strength, which it can draw only from the strength of its members. If but two of its members are dominant in their physical resources and their industrial potential, with the United Nations reduced to the status of an umpire between them, one road to war is open.

As any wise large industrial concern knows, we should invite competition. It will be a safe world if there are several groups nearly equal in strength and if a majority of them agree on peace, for through the UN they have a mechanism for making that agreement itself a peaceful reality. Hence this is but another way of putting the argument that for the UN to be strong, its members must be strong.

I need not here recapitulate the ways in which the United States on the international side of its affairs has met part of its obligation to share its strength with its colleagues. And we know that other commitments must be made. Those on which we have already entered and the others which we realize we must undertake are common-sense commitments, for the common good.

Our national planning must back them up. Our planning must be for a strong United States, strong industrially, economically, socially, and, during the interim years, in a military sense. Whatever the methods that we adopt for solution of the many problems to be encountered in these peacetime years, it is essential that we maintain throughout the nation the solidarity that was one of our greatest sources of strength during the wartime period. There was unity of spirit, unity of endeavor, a vigorous working partnership among the various groups and callings in the population.

The ordinary differences that rise to divide men are sunk and forgotten when national stress demands, for men are then strong enough to merge their wills in the common cause. We must learn to do as well without the spur of emergency, so that the collaboration of good will can come to prevail in times of peace.

But we must not confuse the rigid organization and the

detailed controls of wartime with the unity of spirit that we saw during the war. Should we do so, the temptation would be strong to keep in force extreme regulatory measures, which are necessary and justified only in an emergency. They were not the source of our unity; on the contrary, they were possible only because that unity existed, and they were used to channel that unity as it does not need to be channeled in times of peace. Their purpose was to focus on immediate objectives the freedom of initiative and enterprise that is at the root of our vigor.

It is important for us by sensible degrees to return to freedom of action by the individual. Stifle it, and our strength will wane. This fact must be held in sharp recognition in all we do; such recognition of it is essential to effectiveness in our national planning.

In practical terms, as I see it, this means realizing that planning must organize, regulate, coordinate, correlate activities—even on occasion control them—yet that it must at the same time maintain and strengthen individual enterprise. It is fundamentally the striking of a balance between central authority and pioneering endeavor, adjusting the two so that the first supports and stabilizes the second, and the second vitalizes and stimulates the first. Planning understood as involving this twofold responsibility is essential to any activity of civilized men, in fact, is the hallmark of civilization. By no means does all our planning attain this ideal; as it approaches the ideal, it is effective and socially justified.

A complex technological and industrial economy such as ours, with all the delicate interplay of one element upon the others, with all the often unnoticed interdependence among activities, obviously cannot function without the balancing of forces that planning means. A great deal of

this adjustment is performed by agreement among the different groups and interests operating within the social framework. Much of it remains necessarily to be done by government.

In the allocation of responsibility for planning, I think a good guide was set for us by the able men who wrote the Constitution of this country, reserving to the individual states all powers not specifically given to the Federal government, which that instrument created. So in our day, to government should go the responsibility for that planning which lesser agencies cannot do for themselves and for that planning only.

This means, for example, that, as the public interest demands, regulation of such activities as public utilities must be done by government, for lesser agencies are insufficient. But if interpretation of the phrase "the public interest" is carried to the extent of hamstringing major enterprises or smothering smaller ones, regulation recoils upon itself, initiative is choked, and the public interest suffers by the overreaching, by the mistaking of mere rigidity for planning.

By the same token, in our planning we may bring about serious harm if, looking upon the total industrial structure of the nation, we are misled by its great size and complexity into regarding it as essentially a matured affair, old, settled down, with its days of pioneering far in the past. Nothing could be further from the fact. The United States, it is true, is an amazingly rich and powerful nation, with industry and enterprise diversified and versatile beyond that of any other people. To the casual observer it must easily appear that the extent and the stability of our undertakings are the signs of maturity, that we are resting on our oars.

But not even the majority of our present industry has reached the stage where pioneering is no longer an expected part of its activity. And there lie before us a dozen new fields in which only the earliest beginnings of development have been made. The spirit and the courage of free enterprise never were more needed, never had greater opportunities than in the United States at this moment. Hence there has never been a time when it was more important for men to remember that the essence of good planning is to preserve freedom of initiative and enterprise even while stabilizing and sustaining them by balancing interests and forces in the whole.

Much of the machinery of governmental regulation through which a large share of our national planning reaches expression is of necessity calculated for dealing with large enterprises. This is true in part because it is large enterprises that individually impinge most strongly on the total economy and that therefore set up a need for planning and control exceeding the capacities of lesser agencies than government. It is true also in part because of the fact that much of our existing machinery of regulation reflects the exigencies of wartime, when the necessity of mass production put added emphasis on bigness, occasioned the enlarging of enterprises that had been big in the first place, and led to the grouping of smaller ones into major units.

A consequence of this situation is the fact that the dead hand of bureaucracy lies today too heavily on the controls of smaller organizations in this country, on organizations where regulation, forms to fill out, red tape to unwind, costs more than it is worth. This is the more important because in several of the new fields of enterprise now available to us, pioneering will take form first in small organizations.

If we are to foster the venturesome activity on which new developments so much depend, we must free small organizations of undue paper work, undue trammels and restrictions. In this portion of our system, where about 30 per cent of manufacturing wage earners are employed but where over 90 per cent of our manufacturing establishments are found, we sadly need a return to freedom of enterprise, to a situation in which the employer and his few score of employees tackle their own problems and settle their own differences without the forced intervention of any unwanted and unneeded functionary.

Granted that in the 10 per cent or so of manufacturing establishments which have from a hundred to several thousand employees and which employ some 70 per cent of manufacturing wage earners, the organizational structure may be so complex or the numbers of people involved may be so large as to make desirable occasional oversight by outside agencies. But this is hardly the situation in the smaller establishment, where personal relations are close and opportunities for discussion and resolution are frequent.

To get back to a situation in smaller organizations where the great advantages of freedom of action can be fully realized, we must of course establish conditions assuring freedom of opportunity for the employee who wishes to turn in his time and go to work for someone else. There must be the continuing industrial progress, which creates new fields and new jobs. This brings us back to the issue of planning in science and the issue of the increasing intellectual contribution that scientists may be expected to make to our national life.

More and more, as we all know, American industry and the economic system based on it grow from and are influenced by the fruits of research. In the creation of the

reservoir of jobs needed as a balance wheel in our economic machine, the new industrial possibilities opened by research done during the war years will be a rich source. But we must plan to go beyond them.

To maintain our economic system vigorous and healthy, we must have constant pioneering research. Of all our natural resources, rich as they are, this is the only one which we never need fear exhausting. Nor need we question our ability to pioneer in it, for the record of American science and engineering is proof enough of that, particularly in the applied research that is the immediate precursor of development and hence of industrial operations.

Our planning for science, as a part of our total national planning, must above all else foster and facilitate the creative research spirit. We have a compelling practical reason for this, in the potency of applied research as a source of material benefits and full employment. We have an especially great opportunity in developing the fundamental research out of which applied research grows. The record of American applied science is a proud one; in basic research we have not done equally well, probably partly because we had the great resources of European science on which to draw.

In time to come, we must carry a larger share of the world responsibility for the background of basic science, and this duty must be clearly recognized in our planning. Our best means of securing a peaceful and more abundant life, and our best assurance of continuing strength as a partner in the world enterprise, lie here.

During recent months, American national planning in science has been vigorous and active, with scientists and engineers taking the lead effectively in the long process of

discussion and marshaling of evidence that is the necessary precursor to governmental action. On the domestic front, the most notable example of planning in science as part of national planning is the legislation that will bring into being a National Science Foundation, which will therefore establish formally and firmly an active partnership between government and science.

The foundation as envisaged in the legislation developed through the deliberations of legislators, scientists, engineers, industrialists, and others meets important criteria. It will both support research and further the development of men qualified to lead in the research of the future. It places highly desirable emphasis upon the expansion and furtherance of basic studies. It will contribute substantially to the maintenance of American military strength for the period while that strength continues essential for the reasons that I have suggested. By provisions for cooperation with the United States's own control body and hence with the international control organization that must ultimately be brought into being, the foundation will aid valuably in the world's task of putting atomic energy to peaceful use.

Toward the provision of a sound way for the world to work on this supreme task, moreover, direct intellectual contribution of the highest order has been made by scientists and engineers, in the hard thinking done by the Board of Consultants to the Secretary of State's Committee on Atomic Energy headed by Undersecretary of State Acheson. It was my privilege, as a member of that committee, to follow at first hand the rigorous and able reasoning of the consultants, which was crystallized in the committee report that has been under such wide discussion during the past months and which I per-

sonally feel is one of the greatest state papers of all time.

No better example could be found to support the conviction that the direct intellectual contributions of science to our national life are becoming larger and that a greater part of the justification for science's share in the center of the national stage will come from such contributions. Planning in science and the larger planning in the nation are coming to be more and more closely related. Since this is so, there is profound reason for encouragement and optimism in such accomplishments as our domestic science legislation and the basis that has been laid for American leadership in proposals for international collaboration in the control and development of atomic energy.

The avenue by which scientists have thus entered more closely into our national planning is the right and proper one; their contributions so far have been made principally to those parts of national planning which are concerned with science itself. I believe that scientists, having made their entry this way, can be useful in other ways as well. I am sure, too, that many of them sincerely wish to be useful and that they see issues, problems, enigmas, to the solution of which their particular qualifications can bring much of true value.

As just one example, let me mention our serious need for a more reasonable way of reconciling large-scale industrial differences than the present costly, unhappy procedure. As the industrial machinery of the nation grows more and more complex, interruptions in its functioning grow more and more dangerous. This often means that A's exercising his right to strike robs B of his right to work, and that fact has many serious overtones.

Beyond it, however, is the fact that our present system

could go to the absurd extreme where an infinitesimal minority of the population could throw the entire productive machinery of the nation out of gear. Of course, the public safety calls for reasonable adjustment of all liberties to each other. But we hear some frenzied advocates crying that the right to strike has been abused and should be summarily ended. At the end of that road lies totalitarianism.

To heed this cry would mean to turn away from the democratic system on which we have relied, under which we have grown in strength and happiness, and under which we want our children to prosper even more greatly. The real answer to the problem is more of understanding and more of statesmanship, more of enlightened and effective public opinion, and thus a gradual growth toward a situation that will preserve essential freedoms and preserve also a true industrial progress. This can come only through sincere and studious effort.

There is room here for the attitude toward facts that is characteristic of science, and there may therefore be useful opportunity here for intelligent effort by scientists. Do not mistake me as implying that scientists could provide the answer; I mean only that they may have opportunity to help in seeking it. And there are many other such opportunities.

If scientists are to take a larger part in national planning not directly concerned with science, however, there will be need for better understanding between scientists and nonscientists. In his rather pungent testimony during the Congressional hearings on science legislation, Maury Maverick bore out this assertion by suggesting "that all scientists remember there are other patriots in the world besides themselves and it would be a good idea to develop

some social consciousness. . . . Associating with ordinary people, even politicians, may do the scientists good. As you know, Christ associated with the publicans and the Pharisees—so it won't hurt them to come out."

Mr. Maverick's suggestion indicates a mutual misunderstanding. Scientists and nonscientists, we may judge from his remarks, have been rather wide of the mark in their evaluations of each other. Some scientists, discussing war research, have in all sincerity used phraseology that they would not have used had they understood its overtones in nonscientific minds. Some nonscientists have perhaps been overeager to read into statements by scientists overtones that actually were not there. Each group has not a little to learn about the other and about the innate patterns of operation that the other follows as a result of heritage, training, and natural aptitude.

We recognize research as the exploration of the unknown. The focus of its effort, then, is the new; its orientation—the inherent attitude of the research worker, if you please—is toward the future. Its so-called "laws"—the body of principles to which we sometimes refer glibly as laws of nature—are not laws at all, but generalizations that seek to sum up and correlate the characteristics of a large number of phenomena.

Research deals primarily with external physical facts, objectively observed. When it discovers or uncovers a new phenomenon, research does not tend so much to appraise that phenomenon in the light of existing so-called "laws" and to reject or abandon the phenomenon if it does not conform to them. On the contrary, research characteristically tends to try to bring hypothesis and theory into conformity with the new data.

Though all generalizations, including these, are very

dangerous, I believe it true to hold that in the large these are characteristics of research, of science, and that scientists and other research men tend in their thinking to reflect them. To understand why the scientist is as he is, one must give due weight to these considerations.

Now by contrast, we recognize our government as by tradition, by agreement, and, many would hold, by divine dispensation, a government of laws and not of men. This is but another way of saying that the governmental system under which we operate is essentially a body of agreed abstract principles, which each generation of men interprets and by which each generation of men is guided.

Men to whom the art of government is a first concern, in the sense that research is a first concern to scientists, are and must be profoundly aware of and responsive to the vast accumulation of law, of precedent, of interpretation, that constitutes this body of agreed abstract principles. Though they are, of course, concerned from day to day with new problems, with the issues of the moment, their orientation is greatly toward the past. They deal with external physical fact objectively observed, just as does the scientist. But they deal with it only as and because it produces subjective phenomena in men.

The subjective responses of people are their primary concern. They must rely upon the heritage of law and precedent, for this is their best touchstone, their best criterion, for evaluating the probable subjective results of some new objective fact. They tend to try to bring the new phenomenon into conformity with existing law—and remember that their law, both substantive and adjective, is not hypothesis or theory, but *law*, expressing the will of the people, to be changed only as the wisdom and the will of the people direct, and then only by processes long

some social consciousness. . . . Associating with ordinary people, even politicians, may do the scientists good. As you know, Christ associated with the publicans and the Pharisees—so it won't hurt them to come out."

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Though all generalizations, including these, are very

varied people must give its strength of heart and mind to the common course. For us who as scientists and engineers are familiar with special ways of thought now becoming potentially useful in new and exacting ventures, there are open opportunities and responsibilities greater than we have known. It behooves us, then, if we would fully serve, to seek understanding of ourselves and of our companions.

Commentary

DR. I. I. RABI

Chairman, Physics Department, Columbia University

The remarks of Dr. Bush are very profound and very closely reasoned. I should like to add, or rather emphasize, one important point in which we are in thorough agreement. In planning in science and planning for science, we must have some scientists about whom to plan. We have stopped for almost six years in producing scientists.

We have, during this period, converted many scientists into administrators, others into corpses, and there has been a large degree of attrition, and yet now, as never before, the demands of the country on science and hence on scientists are greater, and projecting it in the future, they will be greater still.

Now one lesson that we learned during the war was the remarkable adaptability of the scientist to new problems. This adaptability surprised nobody more than the scientist, and in thinking about it and trying to find a reason for it, it seems to me that this adaptability comes about from the type of training that the scientist gets.

The scientist is the inheritor of a tradition that is over 300 years old, the continuous tradition stemming from Galileo—I won't trace it farther back. This is a very live and very creative tradition, and by his training he becomes immersed in that tradition. A great deal of the seeming wisdom of the scientist is not his personal wisdom, but he stands on the shoulders of the giants. He is the living expression of this tradition.

Dr. I. I. Rabi, *Chairman*, Physics Department, Columbia University. Nobel Prize winner in 1944 for general application of the resonance method to the magnetic properties of atomic nuclei. Consultant for the Manhattan District project and key figure in development work of radar laboratory at Cambridge, Massachusetts. With aid of Barnard Fellowship from Columbia and International Education Board Fellowship, studied in Europe with Arnold Sommerfeld, Niels Bohr, Wolfgang Pauli, Otto Stern, and Werner Heisenberg. There he became interested in molecular beams and spent considerable time in experimental work, which later resulted in the preparation of numerous important papers published in *Physical Review*. A member of National Academy of Sciences and American Philosophical Society.

I should like to make a few remarks now, since we have so many engineers present, about scientific training and engineering. In my opinion, and I will say this in a challenging way as a physicist, the engineers have been very lax in the training of engineers. To go back to 1939–1940, there were eighty Ph. D.'s graduated in this country in engineering, there were about 200 in physics, and about 800 in chemistry, yet engineering is easily as complex a subject as those two. There is a great opportunity and a great necessity now, before the educators and the industries of this country, to provide for the higher training of engineers.

This is not any argument against the normal course, but it is an argument for an increase in the number of young men who will take advanced training in engineering subjects, who will have the opportunity for a few years after their normal graduation with their engineering degrees, of really getting down to the fundamentals of their subjects, really studying the basic sciences and learning them as they should be learned, and who will then go out into industry and supply that knowledge and leadership and insight that a contact with the living tradition of science will give them.

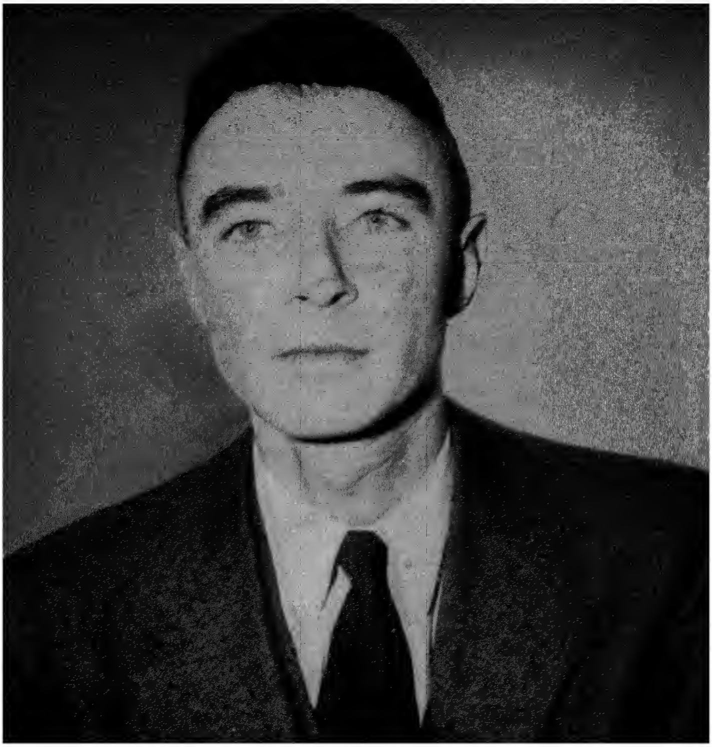
The Future of Atomic Energy

A Future for Atomic Weapons

BY

DR. J. ROBERT OPPENHEIMER

Professor of Physics, University of California and the California Institute of Technology



DR. J. ROBERT OPPENHEIMER, *Professor of Physics*, University of California. A leading physicist and pioneer in the field of atomic research. Joined atomic bomb project in summer of 1942, and planned, organized, and directed special laboratory at Los Alamos, New Mexico, where the atomic bomb was perfected. As head of laboratory, considered "true nerve center of Manhattan Project," made all main decisions and all proved correct. Assembled first bomb at test-firing site. A native of New York, educated at Harvard, Cambridge, and Gottingen. Former professor of physics at California Institute of Technology. Special consultant to State Department on matters of atomic explosives. Member of National Academy of Sciences; fellow of American Physical Society; fellow of American Academy of Arts and Sciences.

A Future for Atomic Weapons

THIS TALK IS TO BE A BRIEF REPORT ON THE FUTURE OF atomic explosives. It will have to be a very incomplete and a very one-sided talk; I can hope that you will agree with me that the part of the matter that I can discuss, if not the most entertaining, is at least the most important.

When I looked over my notes for this talk, I was reminded of a story, very old and not very funny, but relevant. There was a professor of zoology at the University of Munich, and he had the habit of asking candidates about worms, until it came to such a pass that candidates studied no other subject but worms. And then, one day, he flabbergasted his student and said, "Tell me about elephants." The candidate said, "The elephant is a large animal. It has a wormlike trunk. Worms may be divided into the following classes. . . ." My talk to you this afternoon will be along these lines.

I cannot tell you of the probable future technical developments of atomic explosives. When the war was over we recognized that we had only scratched the surface of this problem; and no doubt since then some further progress has been made, both in development and in understanding. But these are things that we cannot talk about here. When, if ever, they can be talked about openly, it will be a very different world, and to my way of thinking a very much better one.

As for the uses of atomic explosives, the one that has been most widely discussed, the one in which their preeminence was first established and is most obvious, is the strategic bombardment of cities. No doubt there can be important tactical applications as well. I have even heard some discussion of the possibility of using them against naval craft. But on these ignorance and inexperience, as well as the requirements of secrecy, keep me from talking. There has even been a little talk of possible beneficent applications of atomic explosives, such as the blasting of polar ice or the possible control of major natural phenomena such as tornadoes, earthquakes, eruptions.

There is enough energy in atomic explosives to give these vague suggestions an air of plausibility; even the weapons so far used release an energy about one-thousandth of that in the San Francisco earthquake. But of course the forces produced by an atomic explosion have a very different sort of order from those involved in the great natural phenomena of quakes and of tornadoes, and the radiation and radioactivities that accompany any major atomic explosion must at least complicate its application to benign purposes. If men are ever to speak of the benefits of atomic energy, I think these applications will at most play a very small part in what they have in mind.

There is only one future of atomic explosives that I can regard with any enthusiasm: that they should never be used in war. Since in any major total war, such as we have lived through in these late years, they will most certainly be used, there is nothing modest in this hope for the future: it is that there be no such wars again. I should like to speak today on some considerations bearing upon the realization of that hope. This is a subject that seems to me worthy of careful study and of the best thought of our times.

Some months ago, I had the privilege of working with a group of consultants to the Secretary of State's Committee on Atomic Energy. We spent many weeks exploring this problem, which is commonly defined in a sort of code as "The International Control of Atomic Energy." This is a code because the real problem is the prevention of war. Since that time our conclusions, expurgated of all secret or classified matter, have been made public and may in one way or another have come to your attention.

They were made public in order to facilitate public understanding and discussion, a discussion made more necessary by the difficulty of the problem, made more difficult by the secrecy that has been maintained and is still maintained about many of its technical elements. What I should like to do today is to add a few comments, which may help to supplement the report that was made public, and to make explicit some of the things left implicit in it, to restore a balance of emphasis that was partially lost, perhaps, in the accidents of its release.

The heart of our proposal was the recommendation of an International Atomic Development Authority, entrusted with the research, development, and exploitation of the peaceful applications of atomic energy, with the elimination from national armaments of atomic weapons, and with the studies and researches and controls that must be directed toward that end. In this proposal we attempted to meet, and to put into a constructive context, two sets of facts, both long recognized and commonly regarded as contributing to the difficulty, if not to the insolubility, of the problem.

The first of these facts is that the science, the technology, the industrial development involved in the so-called "beneficial" uses of atomic energy appear to be

inextricably intertwined with those involved in making atomic weapons. You will hear reports this afternoon on the so-called "beneficial" uses of atomic energy. They come to us not in the form of answers but in the form of questions, and that for two reasons.

In the first place, one of these uses is for the development of power, and this is something that has not been effectively done. No one knows to what extent such power will be economically profitable; no one knows to what extent technical problems may delay or complicate the development of atomic power as power. We have here a beginning, but we don't have any answers. We don't have a tree with fruit ripe on it, for us to shake the fruit down.

The other application is in essence to research; and it is in the nature of research that you pay your "two bits" first, that you go in and you don't know what you are going to see. Therefore, if I speak of "beneficial applications," I want to make it clear that I don't know at all precisely what they are, but I share the belief that is widespread in the American people that a development of this kind in the hands of intelligent and resourceful men will lead to good things. The beginnings of these things you will hear described today.

But one thing I must go into: the same raw material, uranium, is needed for the use of atomic energy for power as for atomic bombs. The plants of an atomic power program may not be ideally suited for the production of bomb materials, but in a pinch—and atomic warfare is a pinch—they can be made to do.

The various fissionable materials derived from uranium and thorium that play such a decisive part in the power program, or even in the use of atomic energy for research reactors and for advancing science and medicine and the

practical arts, are, or can with more or less effort, be made into atomic explosives.

The same physics that must be learned and studied and extended in the one field will help with the other, although there are of course some things in the higher art of bomb making that as yet appear to have no other application.

It is true that the properties that make a fissionable material, that make it useful for reactors for power or for research, are not quite the same properties that make it useful for bombs. Natural uranium can be used in a power plant, but I don't think a bomb can be made of it. Uranium considerably enriched in the isotope 235 can be more flexibly, more effectively used in a reactor; but I am not sure that it can be made explosive and am fairly confident that it would be so ineffective as not to warrant the effort. Even plutonium can be doctored—not without prohibitive cost if it is to be completely nonexplosive—to be made a relatively very ineffective explosive and a difficult one to use in the present state of the art. I don't need to tell you that the art may change and that no kind of control is worth anything that doesn't make provision for such change. It's not only that it can; it probably will, in one way or another.

These differences in the requirements for controlled and explosive uses of atomic energy, might, if appropriately recognized in law, keep a group of individuals from making atomic weapons out of the materials of peacetime industry; they could retard and thus perhaps discourage nations otherwise prevented from the exploitation of atomic energy. But this isn't the problem, for to any who are actively engaged in such exploitation they could provide a deterrent so slight as to constitute a most dangerous illusion.

Thus a mere prohibition on the activities of nations in the field of atomic energy sufficiently incisive to inspire confidence that, if enforced, it would prevent rapid conversion to atomic armament would at the same time close this field to the exploitation of any of its benefits. This fact, which further technical developments appear unlikely to invalidate, has long been regarded as an almost decisive difficulty on the path of international control.

It might have appeared so to us, too, if there had not been a greater one. For even if the course of development of atomic energy for peace were entirely distinct from its development for war, even if it were universally agreed that there were no peaceful applications of atomic energy worthy of interest or of effort, we should still be faced with the fact that there exists in the world today no machinery for making effective a prohibition against the national development of atomic armaments.

In the light of this fact, which to my mind touches upon the heart of the problem, the close technical parallelism and interrelation of the peaceful and the military applications of atomic energy ceases to be a difficulty and becomes a help. This does not, unfortunately, mean that it guarantees a solution, but it does mean that it provides a basis for seeking a healthy solution that would not otherwise exist.

If there were nothing to do with atomic energy but make bombs, there might still, it is true, be a convention between nations not to do so. Such conventions have in the past seldom withstood the strain of rivalries between nations preparing for war, nor does it seem likely that they could do so in the future in the case of a weapon whose effectiveness, especially in surprise, is so spectacular.

For this reason two proposals have long been current

for supplementing international conventions with some form of international action. One of these would set up a scheme of multilateral or international inspection, whose sole function would be to attempt to establish that the conventions were in fact being observed. It is conceivable that if the conventions were sufficiently radical, comprising, for instance, the total renunciation of all mining and refining of uranium, such a procedure might work. But I doubt this, even in that case. I doubt whether the agency entrusted with such inspection could even then have the motivation, or the personnel, or the skill, or the experience, or the knowledge, or the endurance to carry out such a dreary, sterile, and policemanlike job.

I doubt whether the relations between this agency and the nations and nationals whom it was instructed to police would be such as to diminish the nationalism leading to war, or to inspire the confidence of the nations in each other, or to advance the cause of the unification of the world, or to serve as a useful prototype for the elimination of weapons of mass destruction, perhaps equally, perhaps even more terrible.

Therefore one may perhaps not regret that the door to this sort of international action is largely closed by the impossibility of denying to the world in any long term an opportunity to explore the beneficial possibilities of atomic energy. For once such exploration is allowed to the nations, the technical complexities and human inadequacies of an international inspection scheme as a sole safeguard become manifestly insupportable.

The second suggestion for international action to supplement the renunciation by nations of atomic armaments has a more affirmative character. It is that an international agency be entrusted with the making and posses-

sion of atomic weapons. Though there has been much in this proposal that has seemed attractive, it has two weaknesses, probably fatal ones. The more serious is that there is nothing that an international agency can do, or should do, with such weapons. They are not police weapons. They are singularly unsuited for distinguishing between innocent and guilty, or for taking even crudely into account the distinction between the guilt of individuals and that of peoples; they are themselves a supreme expression in a weapon of the concepts of total war.

The second difficulty, in some sense inescapable in any form of international action, but desperately acute in this, is that such stocks of atomic weapons, however earnestly they are proclaimed international, however ingeniously they are distributed on earth, would nonetheless offer the most terrible temptation to national seizure, for the almost immediate military advantage that their use might afford.

These two examples do give recognition to the need, in any system of outlawing atomic weapons, of international action. In this I think they are sound. In fact, in another context, the study—but not the production—of atomic weapons, and inspection to prevent the illegal mining of uranium, both would seem to be essential functions of an international authority.

It is time to turn to the second of the great difficulties that have from the outset been regarded as preventing any effective international control. We have already referred to it. It is the absence in the world today of any machinery adequate to provide such control, any precedent for such machinery, or even any adequate patterns of the past to provide such a precedent. Just this is the reason why the problem is so much of a challenge, why we may be sus-

tained by the hope that its solution would provide such precedent, such patterns, for a wider application.

It did not take atomic weapons to make wars, or to make wars terrible, or to make wars total. If there had never been and could never be an atomic bomb, the problem of preventing war in an age when science and technology have made it too destructive, and too terrible to endure, would still be with us. There would be the blockbuster, the rocket, the V-2, the incendiary, the M-67, and their increase; there would no doubt be biological warfare. There would be, and there still are.

But the atomic bomb, most spectacular of proven weapons, the most inextricably intertwined with constructive developments and the least fettered by private or by vested interest or by long national tradition, is for these and other reasons the place to start. For in this field there is possible a system of control that is consistent with, that is based upon, the technical realities and with the human realities in the deep sense. In this field there is a solution that can be made to work.

Many have said that without world government there could be no permanent peace, and without peace there would be atomic warfare. I think one must agree with this. Many have said that there could be no outlawry of weapons and no prevention of war unless international law could apply to the citizens of nations, as federal law does to citizens of states, or have made manifest the fact that international control is not compatible with absolute national sovereignty. I think one must agree with this.

Many have said that atomic energy could not be controlled if the controlling authority could be halted by a veto, as in many actions can the Security Council of the United Nations. I think one must agree with this, too.

With those who argue that it would be desirable to have world government, an appropriate delegation of national sovereignty, laws applicable to individuals in all nations, it would seem most difficult to differ, but with those who argue that these things are directly possible, in their full and ultimately necessary scope, it may be rather difficult for me to agree.

What relation does the proposal of an International Atomic Development Authority, entrusted with a far-reaching monopoly of atomic energy—what relation does this proposal of ours have to do with these questions? It proposes that in the field of atomic energy there be set up a world government, that in this field there be renunciation of national sovereignty, that in this field there be no legal veto power, that in this field there be international law.

How is this possible, in a world of sovereign nations? There are only two ways in which this ever can be possible: one is conquest, which destroys sovereignty; and the other is the partial renunciation of that sovereignty. What is here proposed is such a partial renunciation, sufficient, but not more than sufficient, for an Atomic Development Authority to come into being, to exercise its functions of development, exploitation, and control, to enable it to live and grow and to protect the world against the use of atomic weapons and provide it with the benefits of atomic energy.

Whatever else happens, there is likely to be a discussion of the control of atomic energy in the United Nations Commissions set up for that purpose, and not in the very distant future, I would say. Should these discussions eventuate in the proposal of an International Authority, and in a charter for that Authority, these proposals and

that charter would in the end be presented for ratification to the several nations.

Each nation, the small as well as the great, can exercise its sovereign right to refuse such ratification. Should that happen, there would be no Atomic Development Authority, and in my opinion probably no trustworthy, effective, international control of atomic energy.

Should a nation, after the creation of the Authority, exercise its sovereign right and withdraw from it, or fail with regard to it to carry out the accepted and major conditions of the charter, then there will also be no Atomic Development Authority; unlike the Security Council, it presumably could not survive the application of the veto to its major provisions. But if it comes into existence, and insofar as it stays in existence, it will provide, in this field, the international sovereignty whose necessity has been so generally recognized.

Perhaps, one will say, no international enterprise can live under such conditions; but the conditions themselves will not remain unaffected by the enterprise. Its coming into existence will be a step that, once learned, can be repeated, a commitment that, once made in one field, can be extended to others. If this is to happen, the Development Authority will have to have a healthy life of its own: it will have to flourish, to be technically strong, to be useful to mankind, to have a staff and an organization and a way of life in which there is some pride and some cause for pride.

This would not be possible if there were nothing of value to do with atomic energy. This would not be possible if the prevention of atomic armament were its only concern, if all other activity was technically so separable and separate from atomic armament that it could remain in

national hands. In the long struggle to find a way of reconciling national and international sovereignty, the peaceful applications of atomic energy can only be a help. It is perhaps doubtful that we should have had a Federal government had not those functions which could not safely or effectively be carried out by the states had a certain importance for the people of this country.

The Board of Consultants to the State Department was aware of the supreme necessity for providing the Authority with work that could attract men and consolidate and inspire them. It was equally aware of the complementary dangers of a too complete, a too absolute monopoly.

These dangers are of two kinds: on the one hand, a monopoly that is not subject to criticism is likely to go to seed; it is likely not to be on its toes; it is likely in the end to become bureaucratically inbred. On the other hand, if you have no living, legitimate contact between the operations of an Authority like this, and the activities of scientists, engineers, and businessmen operating outside the Authority, in national or in private agencies, then you have no way of being sure that you are not missing many important bets. A too absolute monopoly would be dangerous both to the health of the monopoly and to the surveillance activities that an Authority of this kind must maintain.

For this reason we found it important to point out that there were many activities in the field of atomic energy that, either in themselves or because they are easy and reliable to control and inspect and supervise, could not lend themselves to evasive or diversionary developments of atomic weapons.

An example of this kind is the whole field of the use of

tracers. An example of this kind is the use of reactors for research. An example of this kind which is somewhat more marginal, is the use of reactors that burn and do not produce explosive material for power and in which the best steps you can take to complicate and delay the use of this material for explosives have been taken, so that it isn't a thing that can be done in an hour's effort or in a month's effort or by a few angry individuals.

I think the importance of this point is this: there are safe activities that you can leave, for instance, in the hands of the government of the United States or the corporations of the United States or the universities of the United States. For this reason, there will be good, technical liaison between the Authority and these more private agencies. This will, on the one hand, tend to correct the bureaucracy that is implicit in monopoly. On the other hand, it will give the International Authority some method of remaining cognizant of the developments in the field that happen not to have been carried out by itself.

If any great note of confidence or gaiety has invested these brief words, it would be a distortion of the spirit in which I should have wished to speak to you. No thoughtful man can look to the future with any complete assurance that the world will not again be ravaged by war, by a total war in which atomic weapons contribute their part to the ultimate wreck and attrition of this our Western civilization.

My own view is that the development of these weapons can make, if wisely handled, the problem of preventing war, not more hopeless, but more hopeful, than it would otherwise have been, and that this is so not merely because it intensifies the urgency of our hopes, but because it provides new and healthy avenues of approach.

In developing these avenues the fact that there is so far-reaching a technical inseparability of the constructive uses of atomic energy from the destructive ones—a fact that at first sight might appear to render the problem only more difficult—this fact is precisely the central vital element that can make effective action possible. If we are clear on this, we shall have some guide for the future.

Atomic Energy for Power

BY

DR. ENRICO FERMI

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DR. ENRICO FERMI, *Professor of Physics*, University of Chicago. Voluntary exile from his native Italy (where he served as professor of theoretical physics at University of Rome), because of hatred for Fascism. Winner of Nobel Prize in 1938 for work on bombardment of the atom. Authority on energy production in stars. Showed spray of stellar energy on the earth is caused by transformation of hydrogen atoms into helium, thus releasing 20 million degrees (Centigrade) of heat per gram of hydrogen. Under his direction, science of physics was systematized throughout Italy. Professor of physics at Columbia University, 1939–1945; now Charles H. Swift Distinguished Service Professor of University of Chicago Department of Physics and Institute of Nuclear Studies. Author of *Thermodynamics*.

Atomic Energy for Power

I AM GOING TO TALK ON PEACEFUL APPLICATIONS OF atomic energy. It is a subject more pleasant to talk about than the one that Dr. Oppenheimer has discussed. Still, the two subjects are so deeply interrelated that we, unfortunately, cannot expect very much good to come for humanity out of peaceful applications unless a satisfactory solution of the tremendous problems of preventing the destructive use of the military potentialities is found.

If we try to look into the future and we take the optimistic point of view that mankind may succeed in organizing itself so as to eliminate the fear and the danger of atomic weapons, we might speculate as to what may be the development of atomic energy as a constructive force.

Any such speculation, you will realize, can only be exceedingly sketchy. One can point to some probable developments, but one cannot make the list even approximately complete.

The first point that I propose to discuss is the use of nuclear reactions for the production of controlled and usable power. Chain-reacting piles, in which energy is produced at an easily controllable rate, have been operated for over 3 years. Starting with the first pile, which was run only up to 200 watts, the power has been stepped up in successive units by enormous factors. The piles operated at Hanford for the synthesis of plutonium produce energy in amounts comparable to that of the largest hydroelectric plants.

The energy that is produced in the piles built until now, however, is delivered at such a low temperature that it is of no practical use. In the Hanford plants it actually is wasted for the extremely unconstructive purpose of heating, by a small amount, the waters of the Columbia River.

Most of you know, I presume, that the physical basis of the chain reaction is the fission of uranium. This is a phenomenon that was discovered just before the beginning of the war by Otto Hahn and Strassmann working in Berlin. It consists in a very violent disintegration of the uranium atom, which takes place when a neutron strikes it. The atom splits into two fragments, which fly apart with a very high velocity and with a relatively enormous release of energy.

Still, what makes the chain reaction possible is not the large amount of energy released but is the fact that a few neutrons are emitted together with the fission products. If we assume, for the purpose of this discussion, that 2 neutrons are emitted in each fission and also that all neutrons originating in the system produce a fission, we have the conditions that would lead to an explosive chain reaction. Indeed, if in a system of this type we introduce 1 first neutron, this will give rise to fission and produce 2 neutrons. In turn they will produce 2 neutrons each, and so on.

The number of neutrons will then double at each step, or "generation," so that their number will rapidly multiply until the reaction reaches extreme violence and great amounts of heat are developed. This sudden release of energy produces the atomic explosion. The system as just discussed is said to have a reproduction factor of 2, because at each generation 1 neutron gives rise to 2 new neutrons.

In designing a bomb, one tries to achieve conditions in which the fission energy is released as fast as possible. This requires that the generation time be as short as possible and that at each generation the number of neutrons should increase by the largest possible factor. In order to make the generation time short, one will use fast neutrons. In order to make the reproduction factor as large as possible, one will try to adjust things in such a way that a large percentage of the neutrons ends up by producing new fissions and thereby the largest possible number of new neutrons.

If, instead, we want to produce a controllable chain reaction, the reproduction factor will have to be very close to 1 and there will be no need to have a short generation time. Indeed it would be, if anything, more desirable that the generation time be rather long, because this would make control more easy. It is possible, therefore, to use slow neutrons in a controlled chain reaction.

There is one more fundamental difference between the bomb and a controlled chain reaction. The fast reaction on which the bomb is working is operated using "valuable" fissionable materials like U^{235}, which is separated from uranium at Oak Ridge, Tennessee, or plutonium, a new element actually fabricated at Hanford, Washington.

Controllable chain reactions instead can be obtained using natural uranium. This material was used in producing the first chain reaction, for the simple reason that at that time the "valuable" fissionable materials were not available. It also is used in all the industrial piles that have been constructed so far. Natural uranium consists primarily of a mixture of U^{238}, representing about 99.3 per cent of the total, and U^{235}, representing about 0.7 per cent. It is this small amount of U^{235} that makes the reac-

tion possible, since U^{238} does not react, giving rise to fission, when bombarded by slow neutrons.

A chain reaction can be obtained quite easily using pure U^{235}, since thereby one avoids the parasitic absorption due to the U^{238}. When ordinary unseparated uranium is used, the problem is appreciably more difficult, since the positive excess in the neutron balance in each generation is in this case very small, and all unavoidable losses must be kept to a minimum so as to end up with a reproduction factor larger than unity.

From this point of view, therefore, the presence of U^{238} is very undesirable. On the other hand, U^{238} plays a very essential role in the plutonium production. Indeed U^{238} is transformed during the reaction into plutonium by the mechanism represented in the following nuclear process:

$$U^{238} + n \rightarrow U^{239}$$
$$U^{239} \rightarrow Np^{239} + e^-$$
$$Np^{239} \rightarrow Pu^{239} + e^-$$

The first of these reactions represents the absorption of a neutron by the nucleus 238, which is thereby transformed into the isotope U^{239}. U^{239} is an unstable isotope of uranium, which spontaneously disintegrates by emitting an electron and transforming into the new element, neptunium, of atomic charge 93 and weight 239, as indicated in the second reaction.

The transformation of uranium into neptunium takes place in a time of the order of one-half hour. Also, Np^{239}, which is thereby formed, is unstable and spontaneously emits an electron changing in a few days into the final reaction product Pu^{239} as indicated by the last equation. If we examine the over-all balance of a chain reaction of

this type, it is clear therefore that U^{235} will gradually be destroyed to keep the reaction going, whereas U^{238} will slowly be transformed into Pu^{239}.

In order to operate a chain-reacting pile at a steady level, the reproduction factor must be equal to 1. If it is larger than 1, the intensity increases; if it is smaller, the intensity drops. For this reason the operator must have means to adjust the reproduction factor to any desired value in the vicinity of 1. This usually is achieved by means of organs called "control rods." They are rods—made of some material having a strong absorption for neutrons—which the operator can insert into the pile at a depth that can be accurately adjusted.

The number of neutrons absorbed by the rods and thereby removed from the reaction will depend on how deeply the rod reaches into the pile. Consequently, the reproduction factor will also depend upon the position of the rod and will have its largest value when the rod is outside and its smallest value when the rod is completely inside.

Conditions are usually adjusted in such a way that the reproduction factor is equal to 1 when the rod is in some intermediate position called "critical position," and it takes values larger than 1 if the rod is pulled farther out than the critical position, smaller than 1 if the rod is pushed farther in.

If the operator wishes to increase the rate of reaction, the rod is pulled out so that the reproduction factor exceeds 1 by some small amount and the number of neutrons gradually increases. If the operator wants to reduce the rate of reaction, all he has to do is to insert the rods somewhat farther than the critical position. The reproduction factor will then be less than 1 and the rate of reaction will

gradually decrease. If he wants to keep the power at a steady level, he will place the rods at the critical position.

It is clear from this that the problem of controlling the rate of reaction in the pile can be solved in a very simple way. Experiment actually has shown that the controlling problem can also be solved very easily in practice. To keep a pile—whether capable of producing a large or a small amount of power—running at a steady level is an art that can be completely mastered in a few hours. It is also easily possible to keep the intensity of the pile steady at any desired level by moving the rods with mechanical devices operated automatically. In this case all the operator has to do is watch the control panel.

The chief technical difficulty that stands at present in the way of production of atomic energy for practical uses is the following. In all the reacting units that have been constructed until now, the energy is produced at a very low temperature. This undoubtedly is due to a great extent to the fact that the primary purpose for which the piles have been constructed during the war was not the production of useful power, but the production of plutonium. For this reason no effort was made in the direction of constructing a pile with materials capable of standing a very high temperature, since such development undoubtedly would have retarded very considerably the achievement of the essential objectives.

The following points are important. There is no known practical limitation to the temperature at which energy can be produced by a fission chain reaction. Indeed there is reason to believe that, in the explosion of the atomic bombs, temperatures higher than 1,000,000 degrees (centigrade) may have been obtained. Only for machines designed to operate at a steady level a practical limitation

is imposed by the refractory properties of the materials used. In this respect, the choice of the materials is quite critical because not only their ability to stand high temperatures must be taken into account, but also one must consider the adverse effect that adding foreign materials in the reaction system has on the nuclear reaction itself. This adverse effect is due to the fact that most materials absorb neutrons sometimes more and sometimes less. Any material that has to be added as a coolant, for instance, to remove heat from the pile or as a lining for the pipes through which a cooling fluid is conducted determines a loss of neutrons. When this loss is so large that the reproduction factor drops below 1, the reaction stops.

And now comes the question: Could large amounts of energy be released?

The essential fuel in piles of the Hanford type is U^{235}, which represents only 0.7 per cent of the total weight of natural uranium.

The content in fission energy of uranium is roughly 3,000,000 times that of an equal weight of coal. If only 0.7 per cent of the uranium is utilized, the practical uranium to coal ratio will be about 20,000. These figures point to the great importance of devising methods for the complete utilization of the energy of uranium.

The demand for a technical solution of this problem may not be very urgent in the immediate future, since there still are fairly large uranium deposits that can be mined at relatively low cost. If we conceive, however, a development in which large amounts of atomic energy would be produced by U^{235}, the rich deposits of uranium would rapidly be exhausted and further production would have to use very poor ores with a consequent increase of several orders of magnitude in the cost of the primary

material. In this case, the importance of a complete utilization of the energy stored in uranium would naturally become much greater. It is clear on the other hand that the energy value of 1 pound of uranium is so great that even an enormous increase of cost of this material may not interfere with its economical use as a source of power. Three million tons of coal, equivalent in energy content to 1 ton of uranium, cost about $8 million. Consequently, as far as cost of the raw materials, uranium and coal would become equivalent for a price of uranium of $4,000 a pound. Before the war the cost of uranium was about $2 a pound, so that an increase of the order of a thousand times the prewar price would not be necessarily uneconomical.

We might conceive that twenty or thirty years from now the general scheme of atomic energy production may be perhaps about as follows. There will be large central installations in which very great amounts of power will be produced and transformed into electrical energy or steam for local power consumption. Besides producing directly power, these large units may also produce some amount of plutonium, which will be extracted and distributed to small installations in which plutonium and not uranium will be used as the primary fuel. This plan would have the advantage of permitting wide use of relatively small power units, thereby reducing very greatly the difficulties of distribution.

A general scheme of this type has recently been discussed in a report by the State Department, on which Dr. Oppenheimer has made very interesting comments. According to this report, the large central units in which plutonium is produced, as well as all sources of uranium and thorium, would be controlled and operated by an

international agency, which would distribute or sell plutonium in a denatured form for use by individual consumers. The authors of this report express the view that it perhaps might be possible to denature plutonium so as to make its use for military uses exceedingly difficult and time-consuming, and express the hope therefore that it may be feasible to exert only a minimum of international control on the users of denatured plutonium without danger that it may be diverted secretly to construction of weapons.

The attractive feature of this report is, in my opinion, its denial of the chances of success of an international scheme predicated on a set of prohibitions, and prohibitions only. I am afraid, however, that the report may have been somewhat overinterpreted by the public, in an optimistic sense, in its estimate of the difficulties to divert denatured plutonium to military uses. There is no denying the fact that the possible use of plutonium for aggressive warfare constitutes a difficulty for the industrial uses of atomic energy that is much greater than any technical difficulty that we can foresee. The problem of preventing this use is essentially political and not technical, and I do not see much hope of solving it unless the very basis of the relationships among nations should be thoroughly changed in the future years.

Going back to the technical problems, I should like to mention one more feature of atomic energy units that will prove a serious limitation to their general use. During the process of fission, which is basic to the production of atomic energy, not only energy but also radiations of various kinds—particularly neutrons and gamma rays—are produced. Unless they are prevented from doing so by a shield, these radiations escape from the pile and

their intensity is so terrific that they would kill in a very short time any living beings who were to approach an unshielded operating unit. It is therefore an essential necessity to shield the pile with such materials as to prevent the escape of lethal radiations. In principle the problem is not at all difficult to solve. It is sufficient, for example, to surround the pile with a concrete wall several feet in thickness in order to eliminate completely any danger. On the other hand, there is no way to eliminate the radiations without the use of a very heavy shield. Indeed in many designs of piles that have been discussed, the shield represents by far the greatest part of the weight of the installation. The necessity of surrounding the pile with a heavy shield will prevent several uses of atomic power. It does not appear possible, for instance, to design an atomic power unit light enough to be used in a car or in a plane of ordinary size. Perhaps a large locomotive may be the smallest mobile unit in which an atomic power plant conceivably could be installed.

We may summarize this discussion on atomic power by stating that there is definitely a technical possibility that atomic power may gradually develop into one of the principal sources of useful power. If this expectation will prove correct, great advantages can be expected to come from the fact that the weight of the fuel is almost negligible. This feature may be particularly valuable for making power available to regions of difficult access and far from deposits of coal. It also may prove a great asset in mobile power units; for example, in a power plant for ship propulsion. On the disadvantage side we have some technical limitations to the applicability of atomic power, of which perhaps the most serious is the impossibility of constructing light power units; also there will be peculiar

difficulties in operating atomic plants, as for example the necessity of handling highly radioactive substances which will necessitate, at least for some considerable period, the use of specially skilled personnel for the operation. But the chief obstacle in the way of developing atomic power will be the difficulty of organizing a large-scale industrial development in an internationally safe way. This presents actually problems much more difficult to solve than any of the technical developments that are necessary. It will require an unusual amount of statesmanship to balance properly the necessity of allaying the international suspicion that arises from withholding technical secrets, against the obvious danger of dumping the details of the procedures for an extremely dangerous new method of warfare on a world that may not yet be prepared to renounce war. Furthermore, the proper balance should be found in the relatively short time that will elapse before the "secrets" will naturally become open knowledge by rediscovery on the part of scientists and engineers of other countries.

One might be led to question whether the scientists acted wisely in presenting the statesmen of the world with this appalling problem. Actually there was no choice. Once basic knowledge is acquired, any attempt at preventing its fruition would be as futile as hoping to stop the earth from revolving around the sun.

Power production is not the only peaceful use of atomic chain reactions that is in sight. There are other possibilities, which may not compete with the power production in direct economic importance but perhaps may prove to be ultimately the most fruitful field of development. An operating pile is a source of radioactive materials many orders of magnitude stronger than any source

previously obtained. Radioactive materials are produced partly as a direct consequence of the fission process, since the fragments into which the uranium atoms split are radioactive isotopes of elements located in the middle part of the periodic system. These radioactive elements can be purified chemically. Other radioactive substances can be produced as follows: In a going pile, neutrons are emitted continuously in very great numbers. Any substance that is inserted in the pile is exposed to an intensive bombardment by these neutrons. When a neutron strikes the nucleus of a substance, several reactions may take place, and many of them result in the formation of radioactive isotopes. Most elements can be obtained in this way in a radioactive form. Their lifetimes range from a fraction of a second to thousands of years. Among the more significant artificial radio elements, one should mention carbon 14, with a lifetime of about three thousand years. Radioactive substances can be used for a variety of purposes. The radiations emitted by them are equivalent to the radiations emitted by radium and could be used for medical purposes on a much greater scale than has been possible with radium. From the point of view of radiotherapy, the hope has been expressed that it might be possible to take advantage of the fact that the artificial radioactive substances are available in a variety of chemical elements, and one might use the chemical properties in order to achieve a concentration of the active material in the tissue that is to be exposed to the radiations.

Still greater hopes have been raised by the possibility of using large amounts of radioactive materials as tracers. Particularly attractive in this respect appears the possibility of using carbon 14 as a tracer for carbon in organical chemical and biochemical work. The use of carbon 14 in

biology is expected to offer means to follow easily the reaction of carbon in the complicated chemical processes of life, and it is hoped that the availability of carbon 14 will be adequate to allow research in this direction to proceed on a very large scale.

It would not be very surprising if the stimulus that these new techniques will give to science were to have an outcome more spectacular than an economic and convenient energy source or the fearful destructiveness of the atomic bomb.

The Future of Atomic Energy

FROM THE VIEWPOINT OF BIOLOGY AND MEDICINE

BY

DR. W. EDWARD CHAMBERLAIN

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The Future of Atomic Energy

FROM THE VIEWPOINT OF BIOLOGY AND MEDICINE

FIFTY YEARS AGO, ON MARCH 1, 1896, BECQUEREL discovered the radioactivity of uranium. This appears to have been man's initial exploration in the field that occupies our attention this afternoon.

By 1898 the Curies had discovered radium. Soon the biologic implications of atomic energy became apparent through injuries to Becquerel and other workers. Evidence soon accumulated that the rays from radium, along with those from X-ray tubes, could be used with benefit in the treatment of cancer and a number of other diseases. Thus the earliest application of atomic energy to biology lay in the field of medical treatment.

In 1934 the Curie-Joliots discovered artificial radioactivity. The cyclotron, already in operation in Lawrence's laboratory at Berkeley, was soon engaged in the production of radioactive isotopes of a great many of the chemical elements.

Biologists were quick to see the importance of these radioactive isotopes as tracers for the study of vital processes. In the meantime certain developments in the field of clinical medicine were paving the way for a very satisfying integration of the new tool into that field.

The ever-accelerating advance of science exhibits some very human facets. It even follows cycles that might be stigmatized as fashions. A good example is to be found in

the influence which Sir William Osler still wields over the medical world. Osler's system of teaching and practicing medicine, and his approach to clinical research, were emphatically based upon the autopsy. This was good as far as it went, and the discipline that Osler taught must be maintained. Doctors must continue to expose their mistakes and seek new knowledge at the autopsy table.

But how refreshing is the recent shift of emphasis from structure to function! The physiology of an organ—that is to say, the way in which it contributes to the living activity of the body—is surely more important than its anatomy. This emphasis upon vital processes had its modern beginnings in Roentgen's great discovery. The X ray served this purpose not only directly, by permitting fluoroscopic observations of living organs, but indirectly, by its salutary effects upon physics and chemistry and, for that matter, upon the whole world of science. Similarly the new science of atomic energy will benefit biology and medicine not only directly, as when radioactive isotopes from cyclotron, betatron, or chain-reaction pile are put to work as tracers or as therapeutic agents, but indirectly, through the spectacular advances that it has produced and will continue to produce in all scientific thinking.

The word "isotope" recurs frequently in these discussions. For the benefit of those who are not familiar with this term, a brief explanation is offered.

The chemical nature of any atom is governed by the charge of its nucleus—in other words, the number of protons in that nucleus. Thus all atoms with 6 protons in their nuclei are perforce atoms of carbon, while atoms whose nuclei contain 7 protons must be atoms of nitrogen, and so forth. But there are several kinds of carbon atoms, differing from each other in the number of neutrons con-

tained in their nuclei. This causes them to differ in atomic weight, though not in chemical behavior, and they are spoken of as isotopes of carbon and are identified by their respective atomic masses. In the case of carbon, 5 such isotopes have been identified, C^{10}, C^{11}, C^{12}, C^{13}, and C^{14}.

Briefly, carbon 10 (nucleus contains 6 protons and 4 neutrons) has not been found in nature. It has been artificially produced in the cyclotron by proton bombardment of boron. It is extremely unstable. Its half-life is only 8.8 seconds. That is to say, of any given amount, 50 per cent has disintegrated at the end of 8.8 seconds, and less than 1 per cent remains unchanged at the end of 1 minute.

Carbon 11 (6 protons and 5 neutrons) has likewise not been found in nature but has been produced in the cyclotron. Like C^{10} it is unstable. Its half-life is 20.5 minutes.

Carbon 12 (6 protons and 6 neutrons) and carbon 13 (6 protons and 7 neutrons) are stable isotopes. As found in nature, ordinary carbon is a mixture of approximately 99 per cent C^{12} and 1 per cent C^{13}.

Carbon 14 (6 protons and 8 neutrons) is an unstable isotope that is destined to play an important part in biochemical research on account of its very convenient rate of disintegration; its half-life is somewhat greater than a thousand years. It has been produced in the cyclotron from stable nitrogen as well as from stable carbon, but we may expect to recover it in relative abundance from chain-reaction piles like those of the Manhattan District.

From the above we see that isotopes may be *stable* or *unstable*. If unstable, they usually give out ionizing radiations when they disintegrate. This is of immense importance, for it enables us to detect and measure the isotope, with sensitive electroscopes and Geiger counters, when it is present in even extremely small amounts. For examples of

radioactive tracer techniques in biology, iodine is particularly suitable, since the technical methods developed for its use are typical and illuminating.

Iodine is one of the chemical elements that are essential to your health and mine. Our vital processes do not require very much of this element, but a certain small amount of it is absolutely necessary. We have long known that a major share of the body's iodine metabolism is situated in the thyroid gland, but until recently our knowledge of that metabolism, in health and in disease, was extremely limited. We had gone about as far as we could with microscopic study and chemical analysis, using bits of thyroid tissue removed at operation or at autopsy or specimens of blood, and so forth. When radioactive isotopes of iodine became available, doors opened in all directions. For the first time we were in a position to study the living chemistry of iodine without disturbing that chemistry through the introduction of unnatural conditions.

A patient with clinical evidence of *hyperthyroidism* (evidence that the thyroid gland is supplying its characteristic secretion at an abnormally high rate) may be fed a minute dose (a very small fraction of a microgram) of radioactive iodine. If then a Geiger counter is applied over the skin of the patient's neck, the rate at which the iodine becomes concentrated in the thyroid gland can be determined with adequate accuracy.

Since cases of true hyperthyroidism show a characteristic increase in the rate of accumulation of the iodine in the thyroid and in the final percentage of the administered iodine that becomes localized in the gland, our clinical diagnosis in a particular case may be verified or called into question.

There have always been a few cases in which the exact role of the thyroid gland is not clear, and the elevated metabolic rate, hyperexcitability, and so on, may have been produced by some combination of several of the endocrine glands instead of by an overactive thyroid acting alone. It is therefore to be expected that as soon as radioactive iodine becomes generally available, studies of this type will become a routine part of the investigation of practically every case of suspected thyroid dysfunction.

Hypoactivity of the thyroid also exhibits characteristic findings when studied with the tracer technique. The iodine uptake is markedly decreased in rate and in the total percentage of the administered dose that finally becomes localized in the gland. There have already been cases of children with retarded development, clinically diagnosed as hypothyroidism, in which the tracer studies revealed normal iodine uptake in the thyroid, indicating that some other cause for the retarded development must be looked for.

The work with radioactive iodine illustrates another very valuable technique, the so-called "radio-autograph," developed by Hamilton and others. While available also for studies with radioactive phosphorus and certain other radioactive isotopes, the method is particularly informative in the case of the iodine metabolism of the thyroid.

When a patient is operated upon after having swallowed some radioactive iodine, thin sections may be cut from bits of the removed thyroid tissue. If these are placed in contact with photographic film, blackening of the film will occur wherever the radiations from the radioiodine are present in significant amounts. Such a photographic record is called a "radio-autograph." In the illustration (Fig. 1) the left half shows a photograph

made through the microscope of a thin section of thyroid tissue. The right half shows a similar view of the radioautograph of that same piece of tissue. A direct comparison of these two views shows just where the iodine has become concentrated.

An operation may be performed purely for diagnosis, by removing bits of tissue for microscopic study. Such an operation is called a "biopsy." Where cancer is suspected, biopsy is always in order because the correct method of treating a particular case cannot be decided upon until we know a great deal about the character of the involved tissues. By feeding our patient a small amount of radioactive iodine a day or so before the biopsy, the microscopic studies will reveal not only the details sought for in any routine biopsy, but important facts concerning the distribution of the iodine. If the iodine is largely concentrated in such normal thyroid tissue as may remain intact, with the iodine uptake of the cancer practically nil, that case is certainly not suitable for treatment with radio-iodine.

I have dwelt at some length upon this account of the work with radioactive iodine because it illustrates most of the points that should be emphasized in a brief review of tracer techniques. First, isotopes are chemically indistinguishable from one another (until or unless they undergo nuclear change). The atoms of the radioactive isotope mingle with those of the stable element without altering the physiology of the patient (or experimental animal) in any discernible way. So complete is this chemical identity of the isotope and its stable counterpart that Dr. Robley Evans calls the atoms of the isotope "spies" rather than "tracers," thus emphasizing the absence of identifying factors prior to the instant of nuclear disintegration. The

value and importance of this fact of complete chemical identity is self-apparent.

Second, our methods of detecting and measuring the radioactivity of these isotopes are so sensitive (Geiger counters, electroscopes, and the like) that only very minute amounts of the isotope need be used. This is also important, for it means that the total dose of isotope can be kept well below the threshold of biologic effect from the radioactivity. In the case of iodine we have seen that a minute fraction of one-millionth of a gram of the isotope is ample for the tracer technique. In studies of the metabolism (the living-cell chemistry) of sodium chloride, the salt may be traced if but one part in ten billion of the administered sodium is in the form of the radioactive isotope.

Hundreds of isotopes have been identified and intensively studied. A recent compilation listed 276 known stable isotopes, 237 radioactive isotopes whose identification is complete, and more than 200 partially identified isotopes, about which there are varying degrees of doubt.

Of these several hundred radioactive isotopes, relatively few are available as tracers in biologic research. Many are unusable for one or more of the following reasons. Some isotopes disintegrate too rapidly. Excellent work has been done using isotopes with a half-life that is measured in hours, but an isotope with a half-life of a few minutes or seconds can only rarely be applied in biology.

Living tissues contain hydrogen, carbon, nitrogen, oxygen, sodium, phosphorus, sulphur, chlorine, potassium, calcium, iron, copper, zinc, and iodine, in greater or lesser abundance. The isotopes of those elements which are not involved in normal biologic processes are not apt to prove of interest to the biologist. Two notable exceptions are strontium and element 85 ("eka-iodine"). Strontium

has a radioactive isotope with much more useful characteristics than any of the isotopes of calcium, and, since the chemical behavior of these two elements is very similar, strontium may be substituted for calcium in the fluids and tissues of the body. Similarly element 85, which does not occur in nature but can be produced by alpha particle bombardment of bismuth, has been used as a radioactive substitute for iodine.

Some isotopes are not available in sufficient abundance or in sufficient concentration for a particular use, owing to a poor yield from available methods of production. In most instances this limitation is only relative, for it operates chiefly through making the substance more costly.

An isotope may be of little practical use because of inadequate release of energy at radioactive decay. In other words, an isotope that emits a beta particle of such low energy that ordinary techniques do not detect it is apt to be passed over for one with a more generous output. Again, this limitation is a relative one. If a more convenient tracer substance is not available, an isotope with even an exceedingly soft beta radiation may be utilized with special techniques.

It would be difficult to overemphasize the advantages that have accrued to biology and medicine through these tracer techniques. Radioactive iron has brought us important new knowledge concerning the natural history of the red blood cell, the production and consumption of hemoglobin, and the exact fate of the red blood cell when involved in a transfusion. It has been possible to determine which parts of the gastrointestinal mucosa are involved in absorption of iron, in what clinical states iron deficiency is a factor, and what organs and tissues, other than the

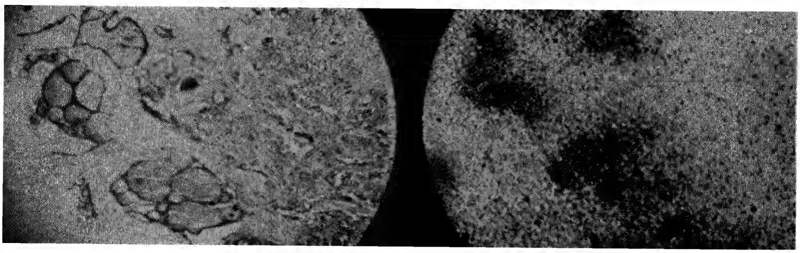

FIG. 1. At the left is a thin section of thyroid as seen through a microscope. At the right is a radio-autograph of the same piece of tissue. The dark portions show where radioactive iodine has become concentrated.

circulating blood and red bone marrow, are involved in iron storage.

Iron, along with sodium, hydrogen, and other tracer substances, has been successfully used in studies into the nature of the placental barrier between mother and fetus. The isotope Fe^{59}, with a half-life of 47 days, is relatively easy to work with, and many more uses will doubtless be found for it in biologic research.

Radioactive sodium has been effectively used for studying the circulation time (the time required for the blood to flow through the arteries and veins and return to the heart). It has been particularly useful in studies of the function of the mucous membrane of the gastrointestinal tract. As a matter of fact, our ideas in this field have been changed drastically by these researches with radioactive sodium. With both potassium and sodium as the tracers, much new light has been thrown on the physiology of the pituitary and adrenals, glands that are much involved in the water metabolism of the body.

Atomic energy does not work alone in these studies. Stable isotopes such as H^2, C^{13}, N^{15}, and O^{18} are also available as tracers and are of great importance. In the case of nitrogen and oxygen, the stable isotopes are the only ones available for tracer work. In the case of hydrogen, important applications have been found for both the stable isotope, H^2, and the radioactive isotope, H^3, but in the past most of the work has been done with H^2.

A similar situation exists in the case of carbon, where the radioactive isotope, C^{14}, must share honors with the stable form, C^{13}. A recent, very startling development made possible by radioactive carbon, C^{14}, is the proof that, in the livers of experimental animals, carbon dioxide is utilized for the production of glycogen.

If time permitted we might record here the fascinating stories of tracer techniques with radioactive isotopes of zinc, calcium, strontium, and sulphur (for example, in studies of the metabolism of vitamin B_1). But of all tracer substances, the one that stands out as the most useful and interesting for the biologist is radioactive phosphorus, P^{32}.

Phosphorus plays an essential part in the metabolism of all living cells. P^{32} is readily produced in the cyclotron by the bombardment of ordinary phosphorus, P^{31}. It has therefore been available in adequate quantities for a good many years, and it has made a place for itself in the study of insect metabolism and even in the study of the metabolism of bacteria. It has been widely used in studies of plant physiology. It tends to become concentrated where growth and new-cell formation are most active. This gives it important implications for cancer research and cancer treatment.

Thus far we have considered mainly those applications of atomic energy that are significant for physiology and diagnosis. What shall we say of its use in treatment? Here we are on fairly familiar ground, for the ionizing radiations from natural radioactive sources such as radium and radon have been used in treatment for nearly fifty years and we have accumulated a great deal of experience in this field. Based upon this experience, certain conclusions may be drawn with a fair degree of certainty.

In the first place, as these new forms of radiation therapy unfold before us, we apparently need to be warned against overoptimism. There is no reason to believe that these new methods of applying atomic energy therapeutically will provide a final answer to the cancer problem. Certain individual cases of cancer will benefit

greatly from treatment with radioactive isotopes or other modalities that involve atomic energy, such as neutron beams. But the differences between such agencies and those which have been available to us for many years are not fundamental. Different sources of ionizing radiations bring differences of convenience and applicability and technique. There are some very important differences between beta and gamma radiations. Differences of "quality" (such as wavelength and energy content) must be taken into consideration.

There is a great weight of evidence, however, to suggest that all these differences are relative rather than basic and that all act through differences in energy distribution, within the patient's body, or within the individual cells of that body. Such differences in energy distribution (perhaps they should be spoken of as differences in the distribution of ionization) are very important. They form the basis for our choice of one or another modality for use in a particular case.

Cancer has been cured by irradiation in many thousands of cases, and the percentage of such good results has increased steadily throughout the years. This improvement has been due in small part to improvements in equipment, in large part to increased knowledge and skill of the radiologist. These newer methods of releasing and applying atomic energy will doubtless prove of real value.

The point is that we must not jump to the unwarranted conclusion that a revolutionary method has suddenly come to hand—one that will solve, or greatly modify, the problem of cancer. With some caution, then, let us look at certain exciting and intriguing aspects of our subject.

We have seen how iodine and phosphorus are selectively concentrated in certain organs and tissues. Physi-

cians were quick to see the implications of this for the treatment of disease. Radioactive isotopes of iodine (and eka-iodine, element 85) were at once proposed for hyperthyroidism and thyroid cancer. Radioactive phosphorus, P^{32}, has now been administered in some hundreds, perhaps thousands, of cases of leukemia and somewhat indiscriminately in various and sundry cases of cancer, of many different cell types and anatomic distributions. In leukemia, radioactive sodium has been used as well as P^{32}. Some work has been done in the treatment of bone tumors with radioactive calcium and radioactive strontium. In the main, the results have been disappointing. The reason may not be far to seek.

Let us consider for a moment the problem of thyroid cancer. Hamilton's radio-autographs have shown that in most cases the iodine becomes concentrated in the secretory epithelium and not in the cancer. This suggests that radioactive iodine may not cure thyroid cancer but may make a place for itself in the treatment of hyperthyroidism. Such has been the practical experience up to the present time. (There is a rare form of thyroid cancer in which the primary growth and its metastases are actively engaged in the production of thyroid hormone, causing the clinical picture of hyperthyroidism. In such a case radioactive iodine may turn out to be of real value.)

The situation with regard to phosphorus is a bit different. Rapidly growing tissues frequently exhibit a high uptake of phosphorus, which is probably due to their high rate of metabolism. Cells that are multiplying rapidly display an appetite for phosphorus that is something to marvel at—and take advantage of. But the difficulty seems to be that certain essential, normal cellular components of the body share this appetite, and when enough P^{32} is administered to

put an end to the tumor we are in danger of seeing also the end of the patient. This point is illustrated by the following case history.

A forty-seven-year-old man suddenly developed a rapidly growing cancer, which became widespread throughout the body even before the appearance of the first signs of the disease. A bit of the tumor was removed for microscopic study. This revealed a cancer of a most malignant and fast-growing type. We gave him 12 millicuries of radioactive phosphorus (P^{32}), orally, in divided doses over a period of three days.

The patient, who had been quite ill, began to improve almost immediately, and by the end of the second week he was back at his law practice, insisting that he felt perfectly well. In five weeks his tumors were gone. Approximately two months after administration of the radioactive phosphorus, the tumors reappeared and seemed to be growing even faster than in the beginning. The general condition of the patient deteriorated rapidly and any risk seemed justified. We decided to administer the largest amount of P^{32} which we had reason to believe the patient could recover from and gave him a total of 40 millicuries in fifty doses of 800 microcuries each, distributed over a period of twelve days. Again the patient manifested rapid improvement and soon presented a picture of well-being.

Knowing that we had exceeded safe limits from the standpoint of the patient's bone marrow and other blood-forming organs, we kept rather close track of his blood picture. One month after the beginning of the second course of P^{32} (18 days after its ending and a little more than three months after the original, 12-millicurie dose), the blood platelets became very few and the patient began to bleed, especially in the gums and under the skin. A few days

later the count showed a severe reduction in the number of white blood corpuscles, elements that are vital to the body's defense against infection.

We combated the tendency toward bleeding by transfusions, with reassuringly prompt results. We administered penicillin in an attempt to combat the danger of infection. For more than two weeks it appeared that we might succeed in tiding the patient over until his bone marrow could again supply platelets and blood cells. Then, suddenly, the patient went into shock and died.

Autopsy showed, surprisingly, no hemorrhage. The cause of death was a generalized blood infection with organisms that are not sensitive to penicillin. (Streptomycin and other promising antibiotics were not available at the time.) No tumor cells could be found anywhere in the body. What appeared, grossly, to be tumor—in the form of leathery layers of tissue around the spine in the region between the kidneys—was carefully studied under the microscope and found to contain no cells. It appeared that every tumor cell had received a lethal dose of irradiation and only the nonvital collagenous supporting structure of the tumor remained. The primary tumor site could not be identified.

A single case proves nothing. I have cited this one in some detail because it indicates fairly well our dilemma in attempting to treat cancer with radioactive phosphorus. Even where the tumor is unusually radio-sensitive, a dose that is safe for the red bone marrow will probably fail to cure the tumor; a dose that is adequate for cure of the tumor may cause the death of the patient.

As suggested a few moments ago, P^{32} has established a definite place for itself in the treatment of certain types of lymphoma (tumors arising in lymph glands or lymph

follicles and allied tissues). Craver and others have reported cases followed long enough for preliminary evaluation. Our own experience parallels Craver's. In the light of our present knowledge and experience it appears that our best method of handling one particularly difficult type of lymphosarcoma (malignant lymphoma) is by combining X-ray treatment with P^{32}. Such combinations of two or more methods of irradiation will probably be developed further as we gain in experience.

Leukemia is a disease in which the blood-forming organs (bone marrow, lymph glands, spleen) produce too many white blood corpuscles. These abnormal, too-numerous white cells do not possess the anti-infection powers of the normal white cells that they crowd out. They also crowd out the normal red cell elements, making the patient anemic. In acute forms of leukemia, treatment with radiation seldom benefits the patient, but in chronic forms of this disease X-ray therapy is a valuable palliative agent. For this purpose P^{32} is apparently at least as efficacious as X-ray therapy and exhibits a number of advantages from a technical standpoint. It seems likely that as P^{32} becomes available in greater abundance, and presumably at a decreased cost, it will tend to supplant X-ray therapy in this disease.

The one disease in which P^{32} has already established itself as the best available remedy is polycythemia vera. This is a disease in which the bone marrow puts out too many red blood corpuscles and the circulating blood becomes too thick to flow normally through the capillaries.

When a patient with this condition is given P^{32}, the radioactive material goes right where it will do the most good, and after a latent period (about a month) the bone marrow begins to behave better. Some caution is necessary.

In spite of its apparent aggressiveness, the hyperfunctioning bone marrow may be quite sensitive to the radioactivity through having partially worn itself out. Dosage should be kept low and repeated when necessary.

Beams of fast neutrons from the 60-in. cyclotron have been given a trial in cancer treatment at the University of California, with some promising results. These penetrate the body only slightly better than 200-kilovolt X rays, but their absorption in the tissues is different, producing enormously denser tracks of ionization. This is reflected in at least a quantitative difference in biologic effect.

The other extreme (lower columnar density of ionization) is provided by X rays of 20 to 100 million volts from Kerst's betatron. Biologic and clinical study of these extremes ought to be continued, even though they are not basically different from the radiation effects that we have long been using.

Possible therapeutic applications of slow neutrons are being looked for. High-energy alpha particles are liberated when lithium and boron capture slow neutrons. Should ways be found to localize either lithium or boron compounds in selected tissues, therapy with slow neutrons might become of practical importance.

Therapy with radiations is very definitely a two-edged sword and should not be discussed without a word or two of caution. Harmful results can be avoided only if the procedures are supervised by people with adequate knowledge and experience. We know what has happened with X rays in the hands of persons uninstructed in the physics and biology of radiation.

A doctor practicing in a small town heard that X ray makes hair fall out. His comely little secretary complained of having hairy arms. Apparently unaware of the poten-

tialities for harm, the doctor administered X ray with his portable radiographic machine. Horrible X-ray burns developed and in due time the young lady's arms had to be amputated.

A professor of chemistry tried to make an ordinary roentgenogram (X-ray shadow picture) of the hand of one of his students, using his crystallography equipment. He must have forgotten about the danger that is ever present when living protoplasm is subjected to irradiation. He must have been very ignorant of the fundamentals of roentgenography. In due time the student's hand sloughed off.

In the beginning of its use, before we have had an opportunity to accumulate experience, a new form of radiation may prove harmful even when used with what appears to have been due caution. This is well illustrated by the following case history.

In 1910, R. S., at the age of twenty years, was given a series of X-ray treatments over the face, on account of a troublesome but not very important acne. The treatments were all administered by a competent radiologist, who knew as much about the subject as anyone did in 1910. At no time during the course of the treatment was there any sign of injury or even of mild reaction. At the time, and for many years thereafter, the effects of the irradiation appeared to have been entirely beneficial.

In 1930, twenty years after the last of the series of treatments, a friend said to him, "Bob, what is happening to your face? Lately it seems to be developing a sort of pinched look that it didn't used to have. And your nose and chin look so pointed nowadays." This was the first inkling the patient had of any injury, though he admitted on questioning that he had noticed his beard grew more

sparsely and more slowly than those of his friends! When I first saw the patient, in 1934, he had developed epidermoid carcinomas (skin cancers) at three points in the damaged field, necessitating extensive plastic surgery as a lifesaving measure.

This case emphasizes an important point. In 1910 we thought we knew how to avoid radiation injuries, but, owing to the latent period that is a feature of all of the biologic effects of irradiation, there were some factors that were not fully understood until many years later. Today we may be unaware of some equally important factors in the therapeutic applications and biologic effects of these newer modalities which have claimed our attention.

In this matter of caution, a sharp distinction should be drawn between serious or malignant disease and unimportant or benign lesions. No one need feel very regretful if plastic surgery becomes necessary twenty years after radiation therapy for cancer. But when the original indication for applying radiation was a few pimples, some superfluous hair, or an evanescent sore spot on a hand, it is quite a different matter.

Attempts to foretell the future of atomic energy require courage, if not foolhardiness. Nevertheless a few things seem to stand out rather boldly as we look at the record. From the point of view of biology and medicine, a truly brilliant future can be predicted for atomic energy, provided its potentialities as an explosive do not lead to the total destruction of our civilization.

Dr. Oppenheimer and Dr. Fermi have been clear-cut and to the point. Should our new-found ability to release, control, and apply atomic energy lead us to disaster, the fault will be a biologic one. That being the case, where lies the hope of our salvation? How best can we implement

the measures suggested by Dr. Oppenheimer for the prevention of catastrophe?

Biology deals with life in *all* its phases. Medicine deals with the diagnosis and treatment of *all* disease, whether physical or mental, organic or functional, individual or involving the entire human race. Insofar as the response of the German people to Hitler's program was a manifestation of abnormal psychology, it is properly a concern of medical science.

The extraordinary achievement of the Manhattan District scientists was a result of tremendous and beautifully coordinated effort for which the whole nation shares the credit. Why should we not embark upon another tremendous and coordinated effort, designed to solve certain pressing questions in human relations? If the greatest of physicists, chemists, and engineers can be brought together for the enterprise that made a place in history for the words "Manhattan District," why cannot the greatest men in the fields of psychology, psychiatry, human history, and social techniques be similarly brought together? With God's help, man's inhumanity to mar might turn out to be a curable disease.

Nuclear Science in Chemistry

BY

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Dr. Hugh S. Taylor, *Dean of Graduate School*, Princeton University. One of nation's most distinguished chemists, played prominent role in mobilizing science for war, directing vital research work. At Princeton laboratories, scene of important exploration into atomic energy, discovered the most effective catalyst for producing heavy water from interaction of hydrogen and steam. Also associate director of experimental plant at Columbia University. Noted authority in catalysis, photochemistry, and chemical kinetics; frequently summoned by industry to solve chemical problems. Member of National Research Council. Awarded many honors, including Nichols Medal of American Chemical Society, Longstaff Medal of Chemical Society of London, Order of Leopold II of Belgium, and Research Corporation Plaque.

Nuclear Science in Chemistry

IN THE ANCIENT UNIVERSITY OF ALEXANDRIA, THERE was a hierarchy of levels in the building, corresponding to the levels of the subject in the hierarchy of learning. Mathematics was on the top floor; chemistry—the black art—was in the basement. In the hierarchy of the sciences involved in the area of atomic energy, once more chemistry resumes its place in the basement, yielding place in the spotlight to the atomic physicists and the biological investigators of tracer atoms.

All that remains, therefore, for me to do this afternoon is to pick up a few of the crusts and the crumbs that have fallen from the rich men's table and reassemble them for your delectation.

The mantle of the prophet sits uncomfortably on the shoulders of the scientist. We are all familiar with the physicists of the early 1890's and their belief that there was no further future for physics than the determination of additional decimal places in the data of physics then known. Nor would the scientist speaking of the postwar future of science in 1919 or 1920 ever have forecast the tremendous advances that the last decade has revealed. All that one can hope to accomplish, therefore, in taking up such a task after the Second World War is to trace the evolution of one's own area of science in the immediate past and venture a short extrapolation into the years immediately ahead. Could one forecast what the brilliant achievement of chemistry ten years from now would be,

one would not be here telling about it, but would most certainly be busily occupied in the laboratory achieving it. That, then, is my apology in advance for what of novelty there is lacking in what will follow, what I can say over and above what my colleagues have said.

The interest of the chemist in nuclear science goes, I would like to observe, back through the centuries to the age of alchemy. But, as we now know, the alchemist was hundreds of years ahead of his time in mind and thought, and his facilities were as inadequate to his projected achievements as the slingshot is to a modern pillbox. The chemist rejected the alchemist's goal and during 200 years busied himself with those aspects of matter which emerge so long as atoms are indivisible. During the eighteenth and nineteenth centuries he could view with pride his many achievements.

The discovery of radium at the close of the nineteenth century and, more especially, the demonstration by Rutherford that the alpha particle was none other than the nucleus of helium newly discovered by Ramsey did indeed tell the chemists that atoms were no longer indivisible, that there was a group of heavy atoms that spontaneously could divide and could in the process hurl out alpha particles, electrons, and, simultaneously, release energy in the form of gamma rays, exceeding in potential that which the scientist could then himself produce in the most efficient X-ray machine.

There ensued revolutionary years of theoretical advances. Einstein emphasized the unitary aspect of matter and energy and in 1905 gave the quantitative formulation in his famous equation $E = mc^2$. This equation taught scientists that, whenever matter could be annihilated, prodigious quantities of energy would result, and it was

Hiroshima and Nagasaki that gave the practical demonstration of that truth forty years later. Rütherford propounded the theory of the nuclear atom, while Bohr extended it in the quantum theory of atomic spectra. The application of the quantum concept to atomic and molecular behavior proceeded empirically through the years until 1924, when Louis de Broglie reversed his field, so to speak, and emphasized the wave aspects of matter. There followed the quantum mechanics of Schrodinger, Heisenberg, and Dirac, with its experimental verification by Davisson and Germer, G. P. Thomson, and Stern. The wave and particle aspects of matter, thus confirmed, strengthened the unitary aspect of matter and energy that Einstein had foreseen and emphasized.

The curve of progress that we need to chart for extrapolation into the years immediately ahead is itself very brief. If dates in essence from the discovery by Urey in 1931 of the heavy isotope of hydrogen and the swift translation of that discovery into the separation of these two isotopes. That achievement made it possible for the chemist to formulate the problems that he could bring to solution with the aid of isotopic nuclei, problems that had hitherto escaped his techniques of measurement. A story drawn from the field of biological science may serve to illustrate the possibilities. It is related that Rutherford, during his Manchester years, had discussed with Bohr and Hevesy, over the afternoon cup of tea, how rapidly the tea passed through the human system, how quickly it would be eliminated. The conclusion was reached, probably reluctantly, that we might never be able to answer that query. When heavy-water concentration was achieved, the answer could immediately be secured.

Hevesy, in Copenhagen then, remembered the occa-

sion and the discussion, used himself as the experimental vehicle by ingesting a beaker of water with a slightly enriched concentration of deuterium, and he traced the elimination of the enriched material through successive stages. The answer that he obtained was at once startling and yet comprehensible when account is taken of the total water content of the human body.

The drink of water I took just before taking my place at this desk will be practically completely eliminated from the system sometime next week but one. This homely illustration may serve as a pattern for all that rich area of "tracer chemistry" that now plays so large a part in the study of biological processes and chemical reaction mechanisms. The isotope has become the chemist's messenger boy in journeys of discovery that without the isotope were entirely impracticable. The years following Urey's discovery of heavy hydrogen were rich in yield of isotopic products with which to venture into this virgin field.

The Einstein relation had revealed that charged particles of extremely high energy would be required to assault the atomic nuclei. Rutherford had used swift alpha particles in his first successful efforts at nuclear disintegration. There followed the man-made nuclear bullets, swift protons, and deuterons, accelerated to the requisite millions of electron volts in voltage multipliers, cascade transformers, van de Graaff electrostatic generators, and finally in the cyclotron.

New forms of atomic nuclei, new isotopes followed. The mass spectrograph charted the stable isotopes of nature. Radiations defined the unstable nuclei. Chadwick in 1932 suggested that in interaction of swift nuclei with light elements—for example, alpha particles and beryllium—a new corpuscle resulted, the neutron of unit mass

and zero charge. Fermi used this new tool to penetrate the nuclei of atoms even to the heaviest, uranium, with results now familiar in the work of Hahn and the nuclear scientists of the war period.

Irene Curie and F. Joliot in 1934 observed that interactions of alpha particles with such nuclei as boron, magnesium, or aluminum produced artificial or induced radioactivity even with light nuclei, electrons, positrons, and gamma rays constituting the principal decay products. Thus, by 1940, the scientist was aware of the existence of 277 stable isotopes and 9 of the naturally occurring radio elements. There were in addition 370 cases known in which the product nucleus was not stable but undergoes further radioactive change. Even with elements such as fluorine—where only one stable isotope, ^{19}F, is known—proton, deuteron, and alpha-particle bombardments of suitable nuclei were shown to yield three radioactive isotopes, ^{17}F, ^{18}F, and ^{20}F, each of them electron emitters.

The tracer techniques were therefore applicable to all elements, either using the mass spectrograph and stable isotopes or, with Geiger counters and other measuring instruments, by use of radioactive isotopes. Such studies were in active progress when war came and with it the swift transition to atomic energy for military purposes.

Prior to the war effort only the stable isotopes of hydrogen, of carbon, and of nitrogen had been separated on anything more than the gram scale. Electrolysis had permitted the production of heavy water by the kilogram, and the exchange reactions developed by Urey for carbon, nitrogen, and sulphur had indicated the possibility of commercial production of the stable isotopes of these elements.

It was the war effort that transformed our concepts of

isotope separation. It permitted the demonstration that electrolysis of water, coupled with a suitable chemical exchange reaction between the effluent hydrogen and inflowing water, could be used to produce heavy water in tonnage quantities as a by-product in any large-scale electrolytic hydrogen-oxygen unit. Much more significant, however, was the demonstration that isotope separation could also be achieved on a plant scale at the opposite end of the periodic table, in the separation of the U^{235} from U^{238}, whether by simple diffusion through membranes, by thermal diffusion, or by the large-scale mass spectrographic technique as developed by Lawrence in the Calutron.

The significance of these achievements for our present purpose may be thus summarized: The large-scale separation of the stable isotopes of hydrogen and uranium, representing the simplest and most difficult cases, has now been achieved. The large-scale separation, therefore, of any intermediate stable isotopes in the periodic system can be reduced to practice whenever the necessity for such is indicated. Separation of the stable isotopes becomes thus what we might term a standard manufacturing technique.

The radioactive isotopes had, prior to the war effort in nuclear science, only been produced in microquantities. Even the powerful cyclotrons or the richest sources of neutrons served only to produce the radioactive products in small amounts. It is true that the techniques of measurement of radioactive materials were so refined that, in special circumstances, only infinitesimal quantities of the radioactive species are required.

I shall cite, by way of example, an experiment by Joris and C. Black in the Princeton laboratory, where they determined the very minute solubility of water in the

lowest liquid paraffin hydrocarbons (in the gasoline range, for example), using less than 1 cubic centimeter of water in a year of research, this water having a tracer constituent not more than one part of radioactive tritium water in a million million parts (10^{12}) of water.

Water of the same concentration was used in another research to determine the equilibrium between tritium water and ordinary hydrogen over suitable catalysts in the temperature range of 25 to 300 degrees (centigrade), and we still will have a lot of the radioactive water left and its half-life as to radioactivity is somewhere of the order of tens of thousands of years.

Uranium fission, on the contrary, presents us with the opportunity of producing a large range of elements in pairs, and the chain reaction, when properly controlled, permits the process to proceed continuously with the accumulation of hitherto impossible quantities of radioactive products. We may represent one such pair of fission products by the nuclear equation

$$U^{235} = I + Y$$

where I and Y stand for the pair of products iodine and yttrium, the latter a rather rare element found in the periodic table of the elements among the so-called "rare earths." These products of fission are radioactive isotopes of the ordinary stable forms of the two elements.

The chain character of the fission process arises from the fact that simultaneously with the production of iodine and yttrium more neutrons are produced than the single neutron consumed in the fission process. The arithmetic will be easy if we assume that two neutrons are produced in each elementary fission process. We can rewrite our equation

$$U^{235} + \text{neutron} = I + Y + 2 \text{ neutrons}$$

These 2 neutrons can in their turn yield 4, 4 yield 8, 8 yield 16, and on up to 32, 64, 128, 256, 512, 1,024. In ten generations there are 1,000 neutrons, 1,000 pairs of products. In twenty generations there are a million, in thirty generations a billion. Each generation requires about 10^{-8} second, so that in less than one-millionth of a second an atomic explosion generating many millions of degrees in temperature and many millions of atmospheres pressure results.

But the scientist knows how to control this chain, prevent the indefinite propagation of the chain by appropriate traps for a fraction of the neutrons produced. He thus can produce a controlled chain reaction, and instead of an atomic explosion he can garner both radioactive fission products and neutron-produced radioactive elements on the scale approximately of 1 radioactive atom product for every neutron captured by practically any of the 92 known elements. It is as a neutron generator that the uranium fission process brings a new technique into the chemistry of the future.

It is now well known that U^{238}, the plentiful isotope of uranium, is one of the elements that can absorb neutrons, especially slow neutrons, to yield the new element plutonium, which is itself fissionable. The process of manufacture of plutonium can be used as an energy producer and at the same time as a source of plutonium to form the neutron generator. Science therefore has two possible sources for all the radioactive isotopes that it needs. It is these new isotopes which will make their mark on the chemical science of the next generation.

What kinds of nuclear reactions do neutrons undergo with atomic nuclei? When the curtain of secrecy fell

around the area of atomic energy in 1939 or 1940, the reactions that had been identified as due to neutrons included nuclear changes that produced alpha particles, protons, gamma rays, and 2 neutrons. Thus neutrons, on collision with boron, gave radioactive lithium plus an alpha particle. We can write this in the form of an equation:

$$^{1}n + {}^{11}\mathrm{B} = {}^{8}\mathrm{Li} + {}^{4}a$$

The superscript at the top left of each symbol indicates the mass of the species to the nearest whole number, neutron = 1, boron = 11, lithium = 8, and alpha particle, helium nucleus = 4. Mass is approximately conserved, but not quite, as we should see if we put the decimal places in after the whole number. The change in mass would emerge as the energy of the two products, following closely the Einstein relation. How did we know that the product was lithium? That can be seen if we rewrite the equation in the following manner:

$${}^{1}_{0}n + {}^{11}_{5}\mathrm{B} = {}^{8}_{3}\mathrm{Li} + {}^{4}_{2}\mathrm{He}(a)$$

In the lower left of each symbol we have written the charge carried by each. The charge of the neutron is zero, that of boron is 5; since an alpha particle (helium nucleus) of charge 2 is formed and since charge is conserved in all such nuclear reactions, the remaining particle must have the charge $0 + 5 - 2 = 3$.

Lithium is the third element and has an atomic number, or charge, of 3. The product is therefore lithium of charge 3 and mass 8. There are only two known stable isotopes of lithium with masses 6 and 7. This lithium produced by neutron bombardment must be radioactive and indeed is so found to be. When it decays it gives off negative electrons or beta particles.

These considerations make possible a much abbreviated shorthand notation, which tells the scientist all the above facts about the boron-neutron reaction. Everything that has just been written about it is summarized in the expression ^{11}B, $n - a$, the element bombarded coming first, the bombarding agent second, and one product third. There is no need to record the product lithium since that follows from the line of reasoning already set forth.

Using this shorthand notation, therefore, the neutron processes known in 1940 included

$$n - a,\ n - p,\ n - \gamma, \text{ and } n - 2n$$

where the products were alpha particles, protons, gamma rays, and 2 neutrons. Also known in 1940 were a series of nuclear reactions in which neutrons were produced by bombarding nuclei with protons, deuterons, and alpha particles. These include

$$p - 2n,\ d - n,\ d - 2n, \text{ and } a - 2n$$

There appears to be no reason why the reverse processes,

$$2n - p,\ n - d,\ 2n - d, \text{ and } 2n - a$$

should not occur. Indeed, with the high-concentration neutron sources that nuclear fission provides, we may expect to record all these processes of change; they may already have been achieved.

When the data are in from all these new neutron studies it is indeed certain that the chemist will have at his disposal many more than the 370 radioactive isotopes of the 92 elements that he knew of in 1940. The larger the range of his knowledge in this area, the better equipped will he be to master the details of nuclear structure and its stability.

In what areas of chemical science will all these isotopes, stable and radioactive, provide new tools for study and research? One example has already been cited in which the course of water through the human body was traced by aid of heavy water. Carbon, nitrogen, phosphorus, sulphur, iron, iodine are among the elements of importance in the complex chemical processes occurring in various physiological systems, both plant and animal. Carbohydrate synthesis and metabolism have been studied with tracer carbon, the fate of red blood cells traced with radioactive iron. The metabolic processes involving phosphorus as registered in the teeth or of sulphur in vitamin B_1 or iodine in thyroxin are typical of researches that are being achieved as the tracer elements multiply. The radiations that the radioactive isotopes emit may well find their own special utility in deep-seated or otherwise inaccessible malignancies.

Already in the area of chemical mechanism the availability of heavy hydrogen has demonstrated the utility that isotopes possess. Disputed mechanisms can now receive decisive test in chemically homogeneous systems, as well as in reactions at surfaces. The studies of hydrogen and water and of heavy hydrogen in compounds, such as ammonia and hydrocarbons, during the 1930's are useful indices of the manner in which catalytic reactions may be elucidated by tracer techniques.

Our knowledge of mechanism in ammonia synthesis and hydrocarbon catalytic cracking is already more certain with studies of heavy hydrogen and heavy nitrogen exchange on catalyst surfaces. It is significant that a company manufacturing gasoline has already undertaken the industrial production of heavy carbon, 13, the stable isotope, while carbon 14, the long-lived radioactive carbon

with a decay period of more than 1,000 years, is promised as a by-product of the uranium pile, for example, by the process ^{14}N, $n - p$.

How isotopes are useful in the problems of mechanism in chemical processes may be illustrated by a very simple example drawn from the prewar studies with heavy hydrogen isotope. Hydrogen reacts on surfaces of nickel with the hydrocarbon ethane, C_2H_6, to yield methane, CH_4

$$H_3C{\cdot}CH_3 + H_2 = 2CH_4$$

This involves breaking the carbon-carbon bond in ethane and adding two hydrogens. By the use of deuterium with the same catalyst and reactant gases, the occurrence of another reaction can be demonstrated that could never be revealed without an isotopic species. This reaction is the so-called "exchange" reaction

$$C_2H_6 + D_2 = C_2H_5D + HD$$

In this case the carbon-hydrogen bond is broken and a carbon-deuterium bond is produced. Experiment shows that this carbon-hydrogen bond reaction goes faster and at a lower temperature on the nickel catalyst than does the breaking of the carbon-carbon bond. We learn thereby something of the rules governing progressive breakdown of complex molecules.

Further experimentation shows that the catalyst also plays a role in the over-all occurrence. There are great divergencies in catalysts with respect to their ability to break carbon-carbon bonds, and it is such knowledge that governs the choice of suitable agents in the hydrocarbon reactions of the gasoline and liquid-fuel industries.

The availability of radioactive isotopes from the nuclear reactions in the uranium pile will increase the utilization of tracer techniques in the area of metallurgy and

metallography. The reactions occurring in metallurgical techniques frequently involve reactions between solids and gases, and it is precisely this area of chemical kinetics that has been the least penetratingly studied by scientists.

Tracer techniques have an immediate applicability to such heterogeneous reaction processes, and the uranium pile—since it is capable of yielding generous quantities of radioactive metals in all areas of the periodic table from light to heavy metals—will notably assist in the prosecution of such studies. Similarly, in the metallography of pure metal and alloy structures, the utility of radioactive tracers will help to solve such problems as grain growth, diffusion through lattices and along crystal boundaries, alloy structures, and superlattices. Here is a rich field for future work.

In analytical chemistry the radioactive tracers may be expected to find service in speeding up the routine analysis of industrial products and intermediates. The possibility for the development of automatic and recording methods based on the measurement of the radiation emitted is at once obvious. Active progress in this area is already under way.

Problems of fluid flow in industrial operations will be immensely aided in their solution by the availability of isotopes both stable and radioactive. Already, as a by-product of the atomic energy effort, the problem of vacuum technique on an industrial scale has been materially assisted. It is now known that huge plants can be assembled which can operate at low pressures with a complete freedom from leaks.

The discovery of leaks by means of a probe gas using rugged industrial mass spectrographs and semiskilled operators is already recorded by P. C. Keith in his account

of the role of the process engineer in the atomic bomb project. Also, by injecting radioactive tracers into any moving mass of fluid, the pathways that the fluid takes and the relative distributions through several paths can be continuously measured and recorded.

There is a further industrial by-product of the atomic energy project that can be mentioned at this particular point, although it does not involve any phase of nuclear science per se. The use of uranium hexafluoride in at least two types of isotope separation demanded during the late war a revolutionary development of industrial technique involving the use of corrosive gases such as fluorine. This development was, at the outset, regarded as even more hazardous than the development of high-pressure techniques for nitrogen-hydrogen mixtures in ammonia synthesis during the First World War.

It is satisfactory to record that the difficulties involved in the handling of such corrosive and highly reactive materials were solved with at least the same measure of success as attended that of the earlier problem of ammonia synthesis. As a result, industry can go forward into a new area of chemical science where reactions which might have been "viewed with alarm" a decade ago will become the commonplaces of chemical industry tomorrow.

The time is at hand when we should go back to our fundamentals of inorganic and organic chemistry to ascertain whether, with the newer reagents and the newer techniques now available on large technical scale, we cannot devise new approaches to old objectives. The chemical engineer emerges from the war effort with newly acquired and generously earned confidence in his own ability to transform any laboratory technique, no matter how complex, into a large-scale technical reality.

We are in such an area of progress today, and especially for the younger scientists is this a golden opportunity. The effort that The George Westinghouse Educational Foundation and other organizations are making, with the object of discovering the younger scientists of the future, means that these young men and women can share in this golden opportunity of progress.

If we, the older scientists, can address to them any word of encouragement, it would seem to me that we might address to them the words which Alfred Noyes has incorporated in his poem of scientific progress, entitled "The Torchbearers," attributed to Tycho Brahe as he hands the torch to his disciple.

> Take thou the splendor, carry it out of sight
> Into the great age I must not know
> Into the great new realm I must not tread.

Commentary

DR. FRANK B. JEWETT

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The effects of the atomic bombs that fell on Hiroshima and Nagasaki were dramatic in more ways than one. They were dramatic in the devastating effects they produced as implements of war; they were dramatic and vivid evidence of the scientific and technical power of a great modern nation and of the might of its vast industrial organization.

In addition they were uniquely dramatic in that they signalized in an awesome spectacle the advent of something with which man had never before had to deal. As a result the term "chain reaction" came almost overnight to be discussed and pondered by a world, the vast majority of whose inhabitants had never even heard the term a few hours before.

Some of the discussion was informed and intelligent, most was necessarily uninformed, and a great deal was fantastic. Substantially all, however, was concerned with the type of physical chain reaction involved in the physics of the bomb. Likewise through it all were threads of deep foreboding or bright hopes for the future that were likely to follow further development of this new force, which science had placed in the hands of man.

Little or nothing was said about another kind of chain reaction that the bombs had set in operation, the chain reaction in men's thinking and acting that was so suddenly initiated.

Unlike the chain reaction of the bomb, which runs its course in a fleeting moment, this other chain reaction bids fair to continue through the ages in much the same manner as the chain reactions of the great religions of preceding times.

Whether men employ the one kind of reaction to guide the other to beneficent or evil purposes, the results seem destined to produce profound effects on human affairs. Whatever the course, it is obviously not something that can be guided by wholly intellectual processes. Whether for good or evil, the results will be determined primarily by the mass reactions of men the world over. Emotions, fears, hopes, and the like will play dominant parts.

That these may be wisely directed toward the good rather than the harm of mankind is the task of education —not education in a narrow scientific sense but broad general education designed to disseminate knowledge of the possibility for good or evil that inheres in the employment of this new force.

This Forum is part of such a long-continuing educational process. Scientists may have started this new chain reaction; they alone cannot control its future. Like most things that spring from scientific research, its social use must necessarily be largely determined by nonscientifically trained men and women. Scientists can and must, however, aid in the general educational process, and it is on occasions such as this that distinguished scientists of real understanding can make noteworthy contributions.

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